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WATER-SUPPLY PAPER 220

GEOLOGY AND WATER RESOURCES
OF
A PORTION OF SOUTH-CENTRAL OREGON

BY
GERALD A. WARING



WASHINGTON
GOVERNMENT PRINTING OFFICE
1908

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GEOLOGY AND WATER RESOURCES OF A PORTION OF SOUTH-CENTRAL OREGON.

By **GERALD A. WARING.**

INTRODUCTION.

OBJECTS OF RECONNAISSANCE.

The rapidly increasing settlement and development of the West which has accompanied the recent industrial expansion of the United States has led to a growth of interest in all of those factors that affect its adaptability to human needs. One of the clearest evidences of this increasing interest is the constant demand for definite and trustworthy information concerning its climate, soils, mineral resources, timber, and water. So great is this demand that the Federal and local bodies which have been organized to study the natural resources are scarcely able to meet it.

In the arid and semiarid sections no question is of more vital importance than that of water supply. Where water can be introduced or developed in abundance colonization will take place; where water exists in limited quantity, sparse settlement is possible; but where water is not to be had present conditions must continue. The water-resources branch of the United States Geological Survey has for many years been making systematic studies of water supplies, both surface and subsurface, and in connection with work under way in many localities, both in the East and in the West, in the fall of 1906 the writer was assigned to carry out a reconnaissance in south-central Oregon.

AREA EXAMINED.

The area examined lies mostly within and includes the greater part of Lake County, so that in the following pages it will often be referred to simply as Lake County. Its location and extent are shown on the index map, Pl. I.

The field work was done, except along the main roads, almost entirely on horseback, for nearly all of the country except the steeper

mountain slopes may be thus traversed. Since much of it is sparsely settled, a light buckboard, on which food, blankets, and horse feed could be carried, was used wherever practicable along the rather widely separated roads.

As no map showing the relief with any approach to accuracy existed, the accompanying topographic map (Pl. II) has been prepared; it is based on field observations with pocket compass and aneroid barometer and on data compiled from all other available sources. Samples of soil and water were also collected for analysis, and rock specimens were gathered for future study. The following report on this region therefore includes a discussion of its present water resources and the development of a greater supply, a statement of its agricultural possibilities, and a summary of the data collected concerning its geology.

ACKNOWLEDGMENTS.

In collecting these data the writer gained much information from the residents of the county, to whom acknowledgment is here made for aid rendered in various ways, both during and since the time spent in the region. Thanks are due especially to Mr. F. P. Light, of Lakeview; Mr. Virgil Conn, of Paisley, and Mr. F. M. Chrisman, of Silver Lake.

PREVIOUS STUDY.

This region has been little studied by geologists or other scientists, partly because, being remote from railroads, it is difficult of access, but mainly, perhaps, because of the monotony of its natural features and its sparse settlement. In 1882 Prof. I. C. Russell made a hasty trip through the region, his observations being embodied in the Fourth Annual Report of the United States Geological Survey.^a The late Thomas Condon, professor of geology in the University of Oregon, crossed Christmas Lake Valley, and Prof. Edward D. Cope also visited the region and published some results of his studies on its fishes and fossils.^b Mr. J. O. Snyder, professor of zoology at Stanford University, has been studying the fishes of its lakes and streams, and the results of his investigations will appear soon in a bulletin of the Bureau of Fisheries; but with the exception of the papers of Professors Russell and Cope, little has been published treating especially of this area. Professor Russell probably visited and studied a greater extent of this northwestern country than any other scientific observer, and many references to his various publications will be made in this paper.

^a Russell, I. C., A geological reconnaissance in southern Oregon: Fourth Ann. Rept. U. S. Geol. Survey, 1884, pp. 431-464.

^b Cope, E. D., The Silver Lake of Oregon, and its region: Am. Naturalist, November, 1889, pp. 970-982; On the fishes of the Recent and Pliocene lakes of the western part of the Great Basin and of the Idaho Pliocene lake: Proc. Philadelphia Acad. Sci., vol. 35, 1884, pp. 134-167.

GEOGRAPHY.

GENERAL FEATURES.

Central and southeastern Oregon lies in the northern end of that great area between the Rocky Mountains and the Sierra Nevada from which no streams discharge into the ocean, and which on this account is known as the Great Basin region of interior drainage.

Lake County is in the northwestern extension of this Great Basin region. To the north, beyond the Pauline Mountains, is the John Day River basin, and to the northwest, beyond the Walker Mountains and other eastern outliers of the Cascade Range, is the valley of Deschutes River; while the Summer Lake "rim rock," known as Winter Ridge, and its mountainous southward extension separate the area herein considered from the Klamath Lake drainage area.

Although this southwestern portion of the county is mountainous, the surface of the northern part and of the region to the east is that of a broken plateau, whose mean elevation above sea level is between 4,500 and 5,000 feet. Over this uneven surface the many depressions either contain shallow lakes or are sinks in which temporary ponds exist only during the wet season. In this plateau region there are no rivers, and even well-defined stream channels are rare.

TOPOGRAPHY.

MOUNTAINS.

The area just referred to, in the southwestern part of the county, is cut into more mountainous relief by the branches of Chewaucan and Sprague rivers, giving it a very different kind of topography from that of the rest of the area considered, in which absence of the type of relief produced by stream erosion is a chief characteristic. On the southeastern border of the Chewaucan River drainage basin an elevation of more than 7,000 feet is reached at several points, while other, more isolated masses, such as Crooks Peak, rise to heights of more than 6,500 feet. The steep mountain slopes back of Lakeview also rise fully 2,000 feet above the valley, and contain two or three summits well above the 7,000-foot contour.

SCARPS.

Although the northern and eastern part of the area studied has the character of a broken plateau, one may travel in some directions for many miles in the level sandy lake valleys or over the approximately level rocky "high desert" without crossing more than an occasional depression. But the chief features that relieve the monotony of the region are the great scarps that have given it the broken character. These trend generally north and south, and the

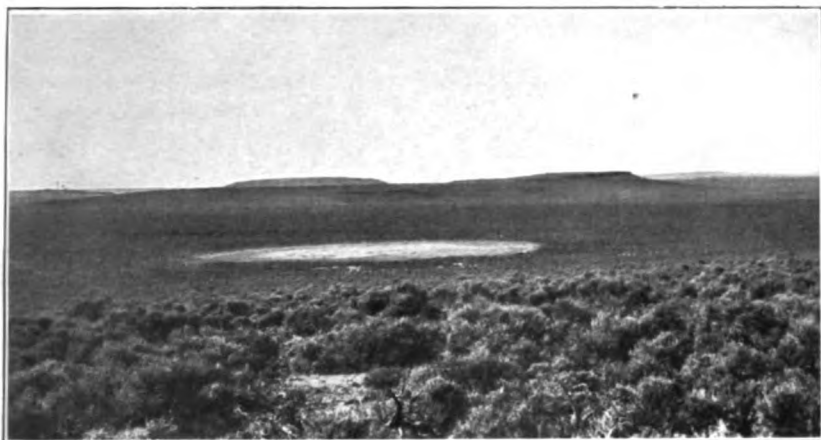
four principal lines border the principal lake valleys, or undrained basins. Along its entire eastern side Warner Valley is thus bounded by a great escarpment, rising to a height of approximately 3,000 feet above the valley floor, while on its western side a lower but also very abrupt scarp limits this valley. Another very prominent line of bluffs marks the eastern edges of the basins of Goose, Abert, and Alkali lakes. Steep but comparatively smooth and rounded slopes mark this escarpment where it forms the western face of the hills above Lakeview and overlooking Goose Lake, but along the edge of Abert Lake it forms a very striking cliff that rises from the water's edge to a height of fully 2,000 feet, the upper 600 feet being nearly perpendicular. The hills north of Lake Abert obscure this feature for a few miles, but along the Alkali Lake basin there is again an abrupt scarp, 1,200 feet in height, which is lower to the north and dies out near the base of Wagontire Mountain. Another scarp, which forms a low bluff near the south end of Lake Abert, extends along the northeast side of Chewaucan Marsh, attains a height of about 1,300 feet opposite Paisley, and passes into the broken country beyond. Although on the western side of this marsh also the hills rise steeply, it is along Summer Lake that the fourth prominent scarp line is best developed, in the ridge named by Frémont "Winter Ridge." Silver Lake is confined on each side by scarps which at its southern end reach 400 feet in height, but these are only a few miles in extent, and are by no means as conspicuous as the others described.

MINOR FEATURES.

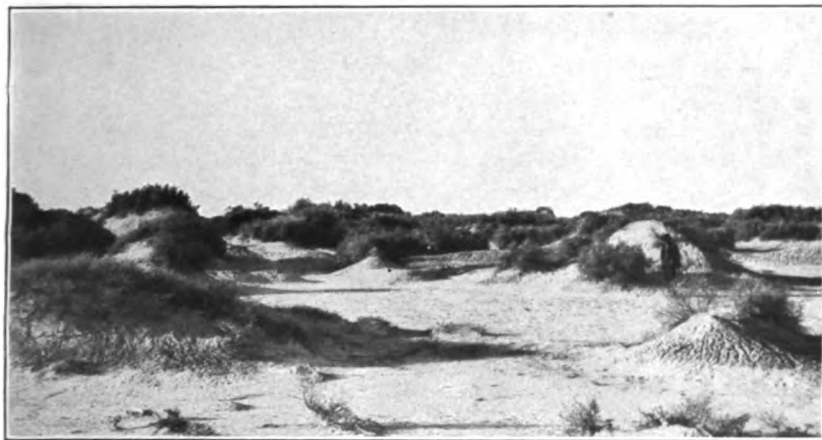
The surface of the rocky plateau area lying between Christmas Lake and Alkali Lake valleys, known as the "high desert," has a minor relief peculiar to itself. Instead of well-defined stream channels, it has a series of long depressions, approximately parallel, trending in a general way from north to south. The larger of these resemble on a small scale the coulées of Washington, described by Calkins;^a they are often limited by nearly vertical walls of basalt approximately 50 feet in height. The bottoms of these depressions are so nearly horizontal as to make it in some instances impossible to tell with the eye alone the direction of the slope. In them a string of sinks or small playas takes the place of a drainage channel. One of these sinks, near the road between Alkali Lake and Paisley, is shown in Pl. III, A. In the spring they may contain a few inches of water, but during the greater part of the year they are dry.

As for other minor features in the northern part of the county, mention may be made of the several mountain masses and peaks

^a Calkins Frank C., *Geology and water resources of a portion of east-central Washington*: Water-Supply Paper No. 118, U. S. Geol. Survey, 1906, p. 42.



A. TYPICAL SINK IN HIGH DESERT NEAR ALKALI LAKE.



B. HILLOCKS NEAR ALKALI LAKE.



C. ALKALINE POOLS IN CHRISTMAS LAKE VALLEY.

that rise above the common level, such as Wagontire and Juniper mountains, and the smaller, isolated mesas and buttes.

In this part of the county, just north of Christmas Lake Valley, there is an area covered with lava and cinder cones representing a very recent period of volcanic activity. Many of these cones or extinct volcanoes are very perfect funnel-shaped craters, and rise directly from the nearly level, though in detail harsh and jagged, surfaces of the lava flows.

The sand dunes near Fossil Lake, in Christmas Lake Valley, illustrate still another topographic type. Extending eastward from this lake, which is only a few acres in extent, is a region of sand hills, fully 6 miles long and averaging perhaps 2 miles in width. The prevailing west wind has heaped the sand into great dunes with steep eastern faces and gentle westward slope. These are slowly traveling eastward and have encroached nearly 3 miles on the part of the "high desert" known as Pine Ridge.

The lower slopes along the western side of Summer Lake are examples of typical landslide topography, and were noted by Russell in 1882. Their principal features are the small basins between the back of the slide and the cliff from which the mass has been loosened, in which water sometimes collects, and the great blocks of tuffaceous material in the landslide débris, whose bedding planes dip in various directions.

Another similar landslide area is that at the southern end of Lake Abert, at the base of the escarpment. It is illustrated in Pl. IV.

Still another minor but interesting feature is to be seen typically developed in the flat near Alkali Lake. Conical hillocks, in many cases 10 feet high, somewhat resembling great haycocks (Pl. III, *B*), and usually topped by greasewood, are thickly clustered on the level surface. Along the borders of the flat these are worn down and rounded off into the more usual "hogwallow" type of mound.

These minor features help much to relieve the monotony of the surface, and, as they are on this account very noticeable, have been thought worthy of brief mention; but the three most significant general features in the topography of this region, and the ones that should be borne in mind in considering the land forms are (1) the great persistent scarps that extend from north to south, (2) the undrained basins at the bases of these scarps, usually occupied by lakes or playas, and (3) the general lack of well-defined drainage over a large part of the surface.

LAKES.

The county has been well named, for besides the larger lakes, Silver, Summer, and Abert, approximately 15, 70, and 60 square miles in area respectively, the Warner Valley chain of lakes and the northern part of Goose Lake lie within the county. Thorn, Christmas, and

Fossil lakes are small water bodies in Christmas Lake Valley, and there are also several large marshes and numerous playas or intermittent lakes. But these numerous water bodies must not be taken to indicate an abundance of water in the region, for it will be remembered that none escapes through surface streams, and that the lakes are only the collecting basins for the run-off from the mountain slopes or the flow from the springs. In a well-watered area with the topographic peculiarities of Lake County the water bodies would be much more numerous and much larger than those that exist there.

CHARACTER OF THE LAKES.

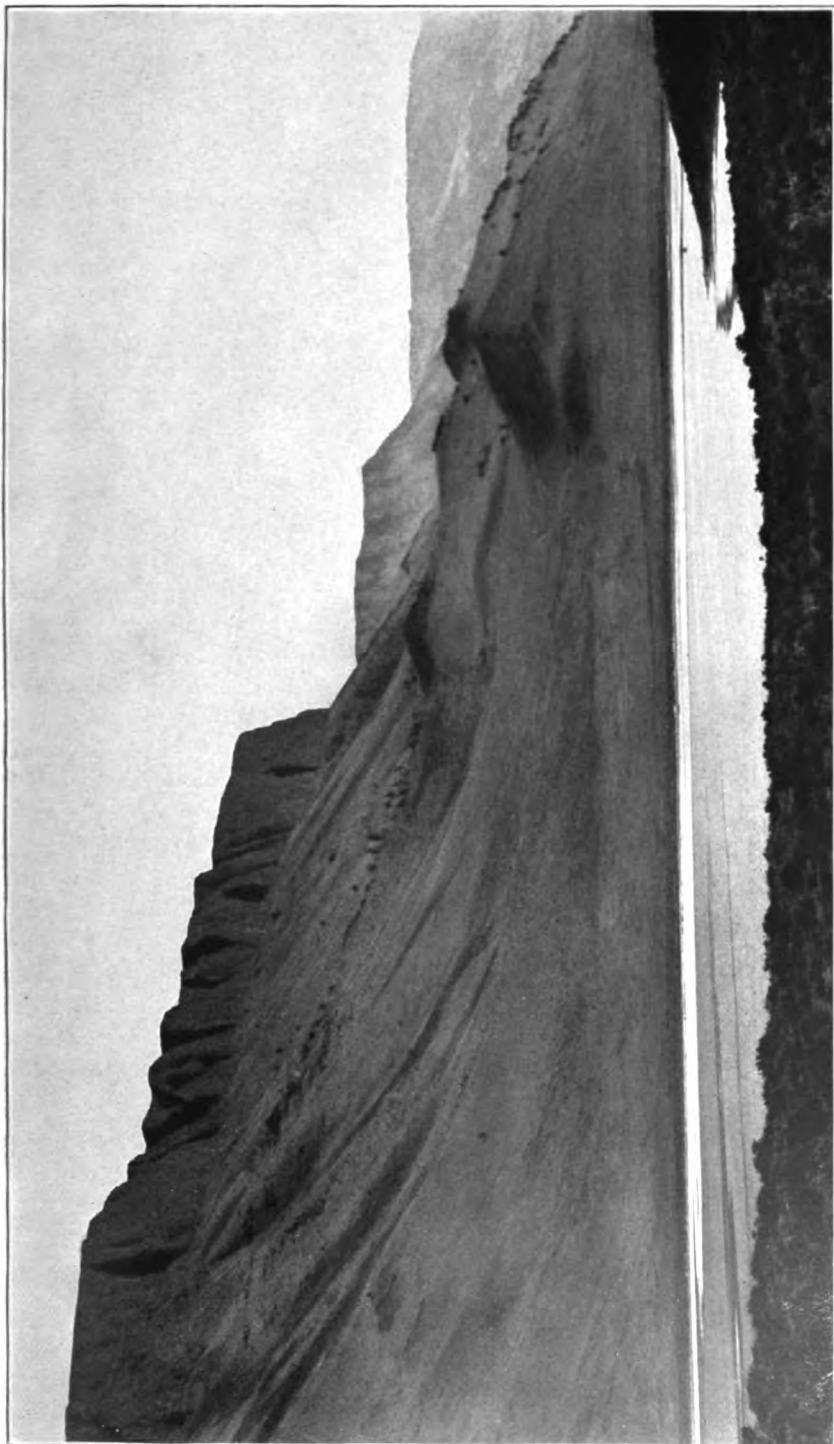
All of the lakes are shallow. None are known to exceed 25 feet in depth, although there is an unconfirmed report of greater depths in the eastern side of Lake Abert. Christmas and Fossil lakes are only 2 or 3 feet deep, while Alkali Lake is really a playa, since during the summer and fall months it is only an alkaline flat containing two or three briny pools.

The size of these shallow water bodies is dependent on the seasonal rainfall, as, indeed, is their very existence. Since the settlement of the country several important changes in their outlines have taken place. During the earlier emigrant days the trail crossed Goose Lake Valley farther south than at present, the place now being under several feet of water. In the early days of Lakeview (now about 6 miles from the lake) the name of the town was not a misnomer, for the lake then extended much farther north than at present, and in 1869 it overflowed for a short time southward into Pit River. In 1881 also it is said to have overflowed for two hours during a severe gale from the north.^a Warner Lake has shrunk during the last half century. The present litigation over lands in its valley hinges on the question whether between 4,000 and 5,000 acres, now dry, was swamp land or part of the bed of the lake at the time of the passage of the swamp land act in 1860. Although before his reconnaissance in 1882 Silver Lake was not known to have gone dry, Russell inferred from its comparative freshness that it must have done so within recent years, since lakes having no outlet are believed to be freshened by desiccation. Therefore the fact that after the exceptionally dry season of 1887-88 the lake did dry up, its bed was taken up for farms, and one season's crops were gathered before the lake again filled, is of especial interest.

ALKALINITY.

Like all lakes having no outlet, those of the area under discussion are alkaline, the waters of Summer and Abert lakes being exception-

^a Russell, I. C., A geological reconnaissance in southern Oregon: Fourth Ann. Rept. U. S. Geol. Survey, 1884, pp. 456-457.



SCARP AND LANDSLIDE AREA NEAR SOUTH END OF LAKE ABERT.

ally so. Russell, in his reconnaissance report,^a gives an analysis of water from Lake Abert, by F. W. Taylor, and remarks that the percentage of potassium salts is greater than in any other lake whose composition is known. But the following analysis of water from this lake is given by T. M. Chatard,^b who says:

The sample was collected by H. T. Biddle at the middle of the west side of the lake, 1 foot below the surface, 30 to 40 feet from shore, September, 1887. * * * This analysis shows, as would be expected, that the water of Abert Lake does not differ materially from that of any other alkali lake so far discovered. Its low percentage of sulphate is its greatest merit [for soda extraction] since it is of all impurities the most difficult to remove and the most deleterious when present.

Analysis of water of Lake Abert.^a

[Average of two samples. T. M. Chatard, analyst.]

	Grams per liter.	Per cent.
SiO ₂	0.232	0.59
K.....	.538	1.37
Na.....	14.690	37.51
SO ₂	.588	1.50
O.....	.118	.30
CO ₂	7.024	17.93
O.....	2.462	6.28
Cl.....	13.462	34.67
H.....	.058	.15
	39.172	100.00
HYPOTHETICAL COMPOSITION.		
SiO ₂	.232	.59
KCl.....	1.027	2.62
NaCl.....	21.380	54.58
Na ₂ SO ₄	1.050	2.68
Na ₂ CO ₃	10.611	27.09
NaHCO ₃	4.872	12.44
	39.172	100.00

^a Chatard says of this analysis (in Am. Jour. Sci., 3d. ser., vol. 136, 1888, pp. 146-150): "The total quantity at my disposal was about 200 c. c., an amount too small for any extended research, but sufficient for all practical purposes. For each determination 25 c. c. (=25.7792 grams) were taken. Specific gravity, 1.03117 at 19.5°."

This analysis, giving a content of about 3.9 per cent of salts, shows the water to be more strongly impregnated than ocean water, which contains about 3½ per cent of mineral salts.

No analysis of the water of Summer Lake is at hand, but a test at its western edge, with the electrolytic bridge,^c indicates a content

^a Op. cit., p. 454.

^b Chatard, T. M., Natural soda, its occurrence and utilization: Bull. U. S. Geol. Survey No. 60, 1890, pp. 50-52.

^c The alkaline salts of natural waters are electrolytes, and the more alkaline a water is the less resistance it offers to the passage of an electric current. Hence by means of an electrolytic bridge, consisting essentially of an electric battery, resistance coils, and a suitable cup to hold the water to be tested, the resistance offered to the passage of the current can be measured, and by comparison of this with the resistance measurements of other waters of which analyses also are available the amount of salts in solution can be roughly determined. Waters containing only 8 or 10 parts of salts in 100,000 are exceptionally pure, and those containing 30 parts in 100,000 are considered very good. The limit for domestic or irrigation purposes is about 400 parts in 100,000, although it depends largely on the character of the salt content.

The average alkaline content of the fresh lakes of North America is given by Russell (Lakes of North America, p. 55), as between 15 and 18 parts in 100,000.

near the shore of 500 or more parts of salts in 100,000. A sample of the efflorescent alkali from its eastern shore consisted almost wholly of the sulphate of soda (Glauber's salt), carbonate of soda (sal soda), and bicarbonate of soda (baking soda).

Similar tests of the waters of Silver and Thorn lakes indicated only about half as great a salt content as the water of Summer Lake. At its northern end Christmas Lake is very alkaline, but at its southern end, where the water is of much better quality, it is fed by an intermittent spring. The efflorescence here, as at Summer Lake, consists of the carbonates and sulphate of soda.

CLIMATE.

GENERAL CONDITIONS.

The climate of eastern Oregon is very different from that of the better known western valleys of Willamette and Columbia rivers, for east of the Cascade Range precipitation is scanty and the region is largely desert in character. The climate is not severe, however. Its temperature has been compared to that of Ohio or Illinois, although its precipitation is much less. The summer days are warm, often excessively so on the rocky plateaus, but the nights are cool, and in some parts of the country frost may be expected in any month of the year. The stormy season is late, February, March, and April often being the most disagreeable months, while open weather sometimes lasts in the fall until Christmas time. On the higher mountains and plateaus snow may lie all winter, but in many of the valleys it melts after each storm.

Weather records have been kept in only two places in Lake County for any length of time—at Lakeview and at Silver Lake. A station was established at Paisley two years ago, and it is hoped that records will also soon be kept at Cliff, near Fossil Lake. In a late bulletin of the Department of Agriculture^a the following statements, especially applicable to Lake County, are made in an article on the climate of Oregon by Edward A. Beals. He says that the seasonal precipitation is chiefly between the months of October and March, with a secondary maximum during May and June, followed by a relatively dry summer. The prevailing winds are southerly in winter and from the northwest in summer, southerly winds being at all times the rain bringers, and in summer causing the lowest temperature. The hot winds are from the northeast in summer, while in winter the cold winds are from this quarter. Thunderstorms occur in spring and early summer, but rarely during the winter months.

^a Henry, A. J., *Climatology of the United States*: Bull. Q, U. S. Dept. of Agriculture, 1906, pp. 498-499.

TEMPERATURE AND RAINFALL RECORDS.

In the tables following are compiled the data obtainable on temperature and precipitation in this region:

Average temperatures and precipitation at Silver Lake and Lakeview, Oreg.^a

Month.	Silver Lake (elevation, 4,300 feet).		Lakeview (elevation, 5,000 feet).	
	Mean temperature in °F.	Mean precipitation in inches.	Mean temperature in °F.	Mean precipitation in inches.
December.....	30	1.2	30	2.2
January.....	29	.8	28	2.4
February.....	30	1.0	29	2.2
Winter.....	30	3.0	29	6.8
March.....	36	1.0	36	1.7
April.....	43	.9	43	1.4
May.....	50	1.2	51	1.7
Spring.....	43	3.1	43	4.8
June.....	56	.8	58	1.2
July.....	62	.6	66	.3
August.....	62	.2	66	.3
Summer.....	60	1.6	63	1.8
September.....	53	.5	57	.7
October.....	45	1.1	49	.9
November.....	36	1.1	38	2.0
Fall.....	45	2.7	48	3.6
Annual.....	44	$\left\{ \begin{array}{l} 10.4 \\ 10.06 \end{array} \right\}$	46	$\left\{ \begin{array}{l} 17.0 \\ 16.73 \end{array} \right\}$
Mean maximum.....	61		60	
Mean minimum.....	28		32	
Absolute maximum.....	104		102	
Absolute minimum.....	$\left\{ \begin{array}{l} \text{July, 1891} \\ -32 \end{array} \right\}$		$\left\{ \begin{array}{l} \text{July, 1896} \\ -24 \end{array} \right\}$	
	$\left\{ \begin{array}{l} \text{Nov., 1896} \end{array} \right\}$		$\left\{ \begin{array}{l} \text{Jan., 1888} \end{array} \right\}$	

^a From Bull. Q. U. S. Dept. Agr., 1906, pp. 966, 969.

^b From First Bienn. Rept., Oregon State Engineer, 1905-6, Pl. I.

Rainfall record at Silver Lake, Oreg.^a

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1889.....											1.48	1.31	
1890.....	1.03	2.74	1.04	0.34	.77	1.46	2.65				Tr.	1.46	
1891.....	.62	3.08	.77	1.46	.77	2.24	1.63				1.50		
1892.....	.12	.91	2.40	.77	2.52								
1893.....	1.50	.75	1.09	.93									
1894.....						.82							
1895.....				1.89	.64	.30	.13	0.39	0.18	0.49	2.32		
1896.....													
1897.....	.25		.80	.25	1.91	2.65	.07	.00	.39	.23	.13	1.47	
1898.....	.27	.30	.15	.22	1.87	.76	.20	.05	.20	.56	2.03	1.38	6.99
1899.....	1.40	.24	2.57	1.02	.49	Tr.	.00	.40	.37	1.44	.75	1.68	10.36
1900.....	.80	Tr.	.31	.53	.90	.42	Tr.	.45	.49	2.09	.40	.95	7.34
1901.....	.08	1.09	.30	.10	.34	.04			1.09	1.31	.57		
1902.....	.24	1.45	.25	2.27	.67	Tr.						2.16	
1903.....	1.73	.55	1.15		.52	.72							
1904.....				.98	.65	.54	1.60	.00		.56	.55		
1905.....			1.03	.70	1.48	2.33	.05	.00	1.34	.55	.23	.07	(?) 7.78
1906.....	1.98	.55	1.89	.38	2.18	1.08	.64	.78			.42	1.68	11.58

^a Station established by Signal Service October, 1889. No instrument shelter used for first few years. Temperature record therefore considered somewhat unreliable, but rainfall thought to be good.

Rainfall record at Lakeview, Oreg.^a

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1890.....						0.23	0.00	Tr.	2.29	0.12	Tr.	1.00	.....
1891.....	0.49	4.95	2.06	1.09	3.00	2.97	.90	0.15	.38	.42	1.07	6.38	24.55
1892.....	2.01	1.57	1.27	2.13	2.04	.67	.06	Tr.	1.51	1.99	3.78	2.47	19.57
1893.....	1.89	2.97	1.74	2.44		.07	.31	.00	1.19	1.59	3.68	1.65	17.51
1894.....	4.66	4.92	3.18	.58	2.24						.97	3.45	
1895.....	5.15	1.02	2.00	.52	1.33	Tr.	.20	.45	.60	Tr.	1.16	2.25	14.62
1896.....	3.55	1.00	2.32	3.94	2.21	.10	.50	.51	1.17	.60	2.96	1.45	20.31
1897.....	1.13	2.95	3.13	1.03	.92	2.09	.10	.10	.86	.36	1.78	1.68	16.13
1898.....	1.40	1.06	.10	.05	1.74	.24	.08		Tr.	.95	1.25	1.50	.....
1899.....	1.44	.80	2.25	1.18	1.10	.20	Tr.	.50	.00	2.60	2.15	2.43	.....
1900.....		1.71	1.04	1.38								1.03	.....
1901.....	3.01	2.58	.59	1.07	.69	Tr.	.00	.27	1.09	1.29	1.73	2.78	15.10
1902.....	.83	3.32	1.41	2.28	2.22	.10	.45	.18	.21	1.17	2.20	2.38	16.75
1903.....	3.59	1.14	1.93	.48	.53	1.23	.46	.32	.06	.44	4.94	.99	16.11
1904.....	1.41	5.45	4.53	2.76	.27	.59	.43	.03	1.10	1.43	.20	3.27	21.47
1905.....	1.67	.73	2.47	.44	1.41	.70	.00	.07	.50	.22	.63	1.08	9.92
1906.....	4.63	1.59	3.14	.53	1.88	1.21	.20	.00	.82	.....	1.52	3.72	19.24

^a Station established by Signal Service January 1, 1884; discontinued October 13, 1888. Reestablished as voluntary station by Signal Service June 1, 1900.

These records, besides showing the much greater precipitation at the southern station, indicate that at Lakeview the climate is also slightly warmer. Although the mean maxima and minima of temperature do not indicate as great extremes in the southern part, the mean seasonal temperatures show that there really is a greater average difference between summer and winter at Lakeview than in the more open Silver Lake region. The difference in these records is probably due more to the difference in elevation of the two observing stations, than to any other single factor. The station at Lakeview is at about 5,000 feet elevation, or 700 feet higher than that at Silver Lake. The former place is also at the base of a range of steep mountains, while the latter is in the open valley.

VEGETATION.

There are few absolutely barren areas in southern Oregon, such as are found in northwestern Nevada and in the Mohave and Colorado deserts. Nearly all of the country produces some sort of natural growth, though in no place is this so dense as to interfere seriously with travel on horseback or on foot. The mountains are rather openly forested with several varieties of pine and fir and with a scattering undergrowth of manzanita, buckthorn, and mountain mahogany. The lack of dense underbrush has no doubt in large measure protected these forests from fires such as yearly burn along the western slopes of the Cascades. The rocky plateaus support a scanty growth of sage and are in some places dotted with junipers, which seem to grow best on the most rocky areas. The growth of pine trees at Pine Ridge, on the eastern side of Christmas Lake Valley, among the dead trunks of junipers, is a unique occurrence in this region, and seems closely related to the soil conditions and moisture as affected by the drifting sands from the valley.

In the sandy alluvial soil of the lake valleys the sage often grows to large size. Three species of rayless goldenrod are also found, chiefly in the valleys and on the borders of playas. On the more alkaline flats, as at Christmas Lake and Alkali Lake, the greasewood seems to thrive best, its young shoots being one of the earliest sources of forage for stock in the spring.

Over nearly all of this area, both in the mountains and on the plateaus, bunch grass and rye grass grow in sufficient quantity to furnish range for thousands of head of stock, while from the marshes many tons of wild hay are cut every year for winter feed.

A number of the native plants were incidentally collected during the study of the region, and were afterward kindly identified by Mr. Le Roy Abrams, assistant professor of systematic botany at Stanford University. Among them are a dozen species of grasses and of desert shrubs, the black sage (*Artemisia tridentata*), common juniper, rayless goldenrod (*Bigelovia*), greasewood (*Sarcobatus*), lupine, and milk vetch or loco weed. In the lake valleys, the marsh elder, bush willow, and buckwheat, with other small plants, were found. On the mountain slopes, besides the forest trees of pine and tamarack, are the buckthorn, manzanita, maple, cottonwood, and quaking asp, together with a number of shrubs and plants of the rose family, among which are the mountain mahogany, cherry, strawberry, and wild plum. The wild plum is found in abundance in several localities. The fruit ripens in September, when it is eagerly gathered by both the Indians and the settlers.

The common horehound and alfilerilla, with one or two other California plants, were noticed along the more traveled roads and around sheep corrals, and have probably been introduced from the south by immigrants and flocks of sheep.

ANIMAL LIFE.

In the late seventies the last mountain sheep were seen in this region. Although deer and antelope have been abundant until recent years, the latter rarely came down into the valleys, and the deer also are now seen mostly in the higher country, as the lower lands are being fenced. The gopher, woodchuck, and hedgehog are found especially in the cultivated sections, and the coyote and rabbit in nearly all parts. Around the lakes ducks, geese, and various other kinds of waterfowl abound, while a few sage hens may be occasionally flushed on the plains. But several varieties of chipmunk seem to be the most common form of wild life, both in the timbered areas and on the plains. The scarcity of birds and other small forms of wild life over much of this region is noticeable.

SETTLEMENTS.

Within the county, comprising 7,834 square miles,^a with a population close to 3,000, there are four towns. Lakeview, the county seat (Pl. V), has a population of about 1,000; Paisley, 300; New Pine Creek, 200, and Silver Lake perhaps 100.

Mail and stage lines, operated six times a week, connect Lakeview with New Pine Creek and Madeline (Cal.) to the south, Bly and Klamath Falls to the west, and Paisley, Summer Lake post-office, and Silver Lake to the north. To the east there is service with Plush, Adel, and Warner Lake post-offices three times a week. Egli post-office, just within Harney County, has communication twice a week with Riley and Burns to the northeast. In the newly settled Christmas Lake Valley provisional post-offices have been established at Lake and Cliff, with weekly service to Silver Lake.

The nearest railroads are at Madeline (narrow gage), 95 miles south of Lakeview; Weed (Cal.), and Pokegama (Oreg.), each about 135 miles west of Lakeview; and Shaniko, 166 miles (according to the post-route map) northward from Silver Lake. The latter place indeed claims to be farther from a railroad than any other post-office in the United States. A railway route has recently been surveyed through Christmas Lake Valley, however, and it is hoped that work will soon be begun on the line and that Silver Lake will not hold this unique distinction very much longer.

Except near Lakeview the county roads do not receive much care, and in consequence travel over those least used is slow.

The freight rate between Shaniko and Silver Lake, by teams, is 1½ cents a pound; so that prices of all heavy or bulky supplies that have to be shipped in, especially grain, flour, and potatoes, are high.

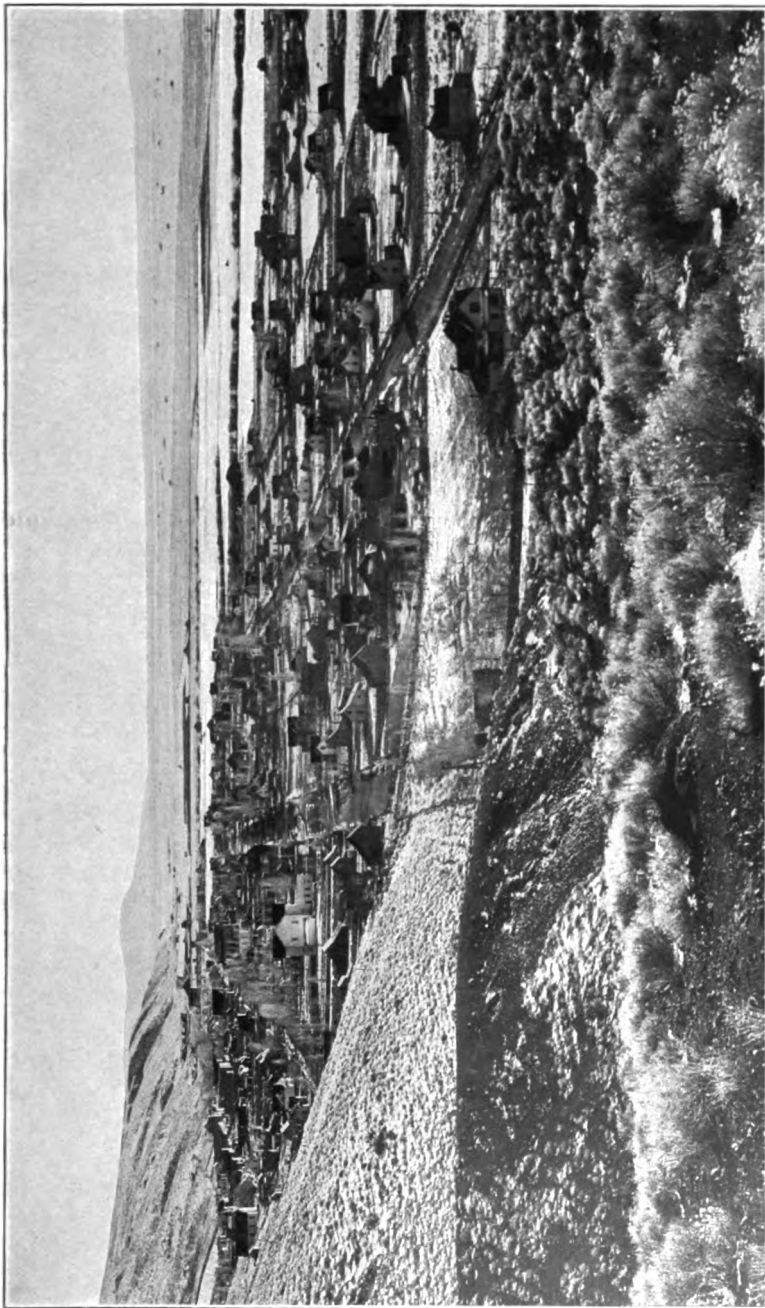
Telephone lines connect the settlements with the railway points, and several cooperative lines connect most of the isolated ranches. Quick communication may thus be had throughout much of the county. In other matters, too, the people are progressive. Lakeview has a water system supplied by springs in the mountains above the town, and both it and New Pine Creek have electric lights, while several buildings in Silver Lake are also furnished with electric light from the plant of Mr. F. M. Chrisman, which uses power generated by a distillate engine.

INDUSTRIES.

GRAZING.

On account of the presence of natural forage grasses and the unfitness of much of the country for any other purpose stock raising has become the chief industry. Horses and cattle roam in great numbers

^a Gannett, Henry, The forests of Oregon: Prof. Paper U. S. Geol. Survey No. 4, 1902, p. 25.



LAKEVIEW, OREG., FROM THE NORTH.

over the plateaus or "high desert," and are owned chiefly by the interests that control the hay ranches of the marsh lands. The scarcity of water in summer limits the range of cattle during that period to the mountains or, on the desert, to the vicinity of water holes. They are usually rounded up for feeding on the marshes during the severe weather of the early spring months. Horses, being able to travel more rapidly, can range farther from water than cattle, and often become so wild that it is almost impossible to collect them for branding or for market. It is said that a band now roams the lava beds in the northern part of the county, and that determined efforts for several years have failed to capture them, because of their wildness and the rough character of the lava surface.

Sheep also constitute an important factor in the county's wealth. During the summer months the flocks are kept in the mountains, where water can be obtained, and are not brought down into the valleys until November or December, when sufficient snow has fallen to furnish water during the winter.

AGRICULTURE.

Comparatively little farming has yet been done, although most of the fruits and vegetables consumed in the county are raised along the eastern side of Goose Lake and the western shore of Summer Lake. Apples and potatoes are the staples, but the farms near New Pine Creek are also noted for their melons. Nearly all garden vegetables can be obtained during the summer and early fall months, in spite of the fact that frosts are likely to kill the more tender plants. It is the general opinion that more extensive cultivation is lessening the tendency to early frosts, and it is claimed that vegetables, such as tomatoes, can now be grown in several places in the county where formerly they could not.

A number of small dairies, sufficient to supply the local demand for milk and butter, are established in Summer Lake and Goose Lake valleys, but little or none of their products are shipped out.

At Paisley and on the western side of Summer Lake, where water for irrigation is obtained, there are several alfalfa fields, and in these localities a few fields of barley and rye are also grown.

LUMBERING.

Three or four small sawmills supply the local demand for lumber, the price at the mill being about \$12 a thousand feet board measure. Yellow pine furnishes nearly all the timber, and also supplies fuel for heating and other purposes, as there is no coal in the region. Gannett^a estimates the stand of merchantable timber in Lake County as

^a Gannett, Henry, *The forests of Oregon*: Prof. Paper U. S. Geol. Survey No. 4, 1902, p. 16.

3,106,000 feet board measure, all of which is yellow pine, the average stand to the acre being 3,000 feet.

MINING.

Near New Pine Creek there has recently been some gold-mining excitement, but in a district a little south of the State boundary. The only prospects worthy of mention within Lake County are those of the Coyote Hills, in what is known as the Lost Cabin gold mining district. This district was brought to the notice of mining men in August, 1906, by the Loftus brothers. The value and extent of the deposits have not yet been proved. Such values as have been found are in oxidized ores in andesitic breccias, a mass of these more acid rocks beneath the basalts that are so generally distributed over Lake County forming the boss exposed in the Coyote Hills.

The alkaline flat at the southeast end of Summer Lake has been located for soda, and a part of Alkali Lake as borax claims, but no development work has been done in either locality.

A small quantity of saltpeter (nitrate of potash) of high quality has been found on the northwestern side of Wagontire Mountain, but the character and extent of the deposit are not known.

HISTORICAL NOTES.

Some historical notes on the county have been assembled in a "History of Central Oregon,"^a and the following extracts may not be out of place here:

As early as 1838 a form of government was exercised by the Methodist Missions in "Oregon," and two years later a petition for a civil government was sent to Congress by the people settled on Puget Sound and in the tide-water region of Columbia River. In 1838 Col. J. J. Abert prepared a map showing Warner Lake and other natural features of the eastern country, from data procured by trappers and explorers of the Hudson Bay Company, but Col. John C. Frémont seems to have been the first to cross the area now Lake County, and to bring out a clear account of the region. He left The Dalles in November, 1843, on the return trip of his exploring expedition, traveling southward to Klamath Marsh, then eastward across Sycan Marsh. Here the explorers were overtaken by a heavy snowstorm, and when they suddenly came to the edge of the cliff overlooking Summer Lake and saw the valley below green and inviting they bestowed the name of Winter Ridge on the bluff and its present name on the lake at the foot of the bluff. After traveling past Chewaucan Marsh and Lake Abert, which Frémont named after Col. J. J. Abert, chief of the Corps of Topographical Engineers, under whose instructions he was working,

^a An Illustrated history of Central Oregon, compiled by F. A. Shaver, Arthur P. Rose, and R. F. Steek. Western Hist. Pub. Co., Spokane, Wash., 1905.

they reached Warner Valley on December 23, and spent Christmas day on the edge of the lake, which they called Christmas Lake. Thence they traveled southward to Pyramid Lake and into California.

Nearly six years later, in 1849, Capt. William H. Warner, United States topographical engineer, explored the country north and east of Goose Lake for an emigrant trail from Sacramento, and was killed by Indians in the valley now bearing his name. It was not until the early sixties that the country was again penetrated by whites, when the discovery of gold in the John Day and Powder River regions led to the establishment of the military post of Fort Klamath along the route of travel from California and Nevada to the new mines. There was also a line of travel between Steins and Warner mountains, leading later to the establishment of Fort Warner. So, although without a settler, Lake County was traversed by a number of parties during these years.

In 1868, when as a result of General Crook's campaign the Shoshone Indian war ended, immigration began. In 1872 a weekly mail route was established between Ashland, Oreg., and Lake City, Cal., with a post-office at New Pine Creek. Four years later a post-office was established at Lakeview. In 1874-75 a post-office was established on the western side of Silver Lake, the town of Silver Lake not being founded until 1886. There were several settlers at Paisley in 1871, and seven years later a store was opened at that place. The county of Lake was formed in 1874. At first it included the present Klamath County, but did not contain Warner Valley, and it did not receive its present boundaries until 1886.

GEOLOGY.

CHARACTER AND AGE OF ROCKS.

In studying the geology of the region—the kinds of rocks and their structure—all of the consolidated materials that were seen are volcanic effusives and related volcanic muds, or tuffs. These rocks belong to several lithologic classes and to more than one geologic period, but by far the most extensive series is that of the basaltic flows. These cover nearly all of Lake County and extend eastward beyond Steins Mountain and northward beyond the John Day region, where fossils that have been collected from interbedded sedimentaries determine the age of the flows as Miocene.

No such fossil-bearing beds were found in the Lake County area, and the effusive material was not traced in detail to the place where such beds are exposed. But the material is so similar in lithologic character, in the amount of deformation it has undergone, and in its general relation to the Cascade Range to the west that there is little

hesitation in placing it in the same general series with the widely extended and well-known Miocene lavas of Washington and northern-central Oregon. Although these Miocene basaltic lavas cover nearly all of the region examined with the exception of the lake valleys, there are sufficiently large areas of lavas of other types to warrant a preliminary separation into three groups—older acidic effusives, older basaltic effusives, and recent eruptive material. These are tentatively mapped, with their approximate areas, so far as these could be determined in a rapid reconnaissance, on Pl. VI (in pocket).

CLASSES OF ROCKS.

OLDER ACIDIC EFFUSIVES.

The rocks of several mountain masses in this region differ enough from the more common basalts, both in the nature of the topography to which they give rise and in their petrologic character, to warrant us in considering them as belonging to an earlier period of more acidic effusion, when the lavas poured out were andesites, rhyolites, and related obsidians. They are perhaps of early Tertiary or pre-Tertiary age. In the succeeding effusions the materials were either basaltic or tuffaceous.

The Coyote Hills and Rabbit Hills masses are placed in the older class because they are composed largely of a light-colored glassy or porphyritic rock that seems to have been disturbed and eroded before being surrounded by the basaltic flows. These lavas are much more acid than the surrounding basalt, and they are regarded tentatively as rhyolites, andesites, and trachytes. In three other places—near Lakeview, near the head of Chewaucan River, and between Silver and Summer lakes—similar rocks were found. Slides of these were examined by E. S. Larsen, jr., and identified as andesite.

Gray Butte, Big Juniper Mountain, and Horning Bend are composed of light-colored rocks that appear also to have been disturbed and eroded before the outpouring of the later basalts. They are rhyolitic in character.

The general form of Wagontire Mountain and its relation to the basalts that dip westward away from it suggest that it also may have been produced by an earlier, possibly local effusion, uplifted since the outpouring of the basalt flood. On its westward side a glassy andesite was found, but the rocks of the eastern portion are more crystalline in texture and apparently more basic.

The black obsidian of the Glass Buttes, to the northwest, and of Horse Mountain, to the southwest, is probably related to the Wagontire Mountain mass.

OLDER BASALTIC EFFUSIVES.

Basalts.—The basalt of the main flows over the surface of the country is for the most part a dark-gray, fine-grained, rather vesicular rock, weathering on the more level areas into brown rounded cobbles and boulders that make a very uneven surface, difficult to travel over.

On the higher peaks the more resistant types of this rock contain much iron and strongly affect the compass needle. Very little soil has formed over these high desert areas. Approximately parallel partings, usually at intervals of only a few feet, mark the division between successive flows, but in some places much thicker beds are exposed. Fissures nearly perpendicular to the parting planes break the basalt into blocks, which by transverse fracturing are reduced to smaller and smaller fragments, forming the characteristic talus slopes of the cliffs.

Tuffs.—In several places over the northern and western parts of the county there are remnants of a great tuffaceous flow or series of flows. This tuff underlies the upper flows of the basalt, but probably belongs to the same general period of effusion. Fort Rock (Pl. VII, A), an isolated mass in the northwestern part of Christmas Lake Valley, is the most prominent of these remnants. It is imperfectly crescent shaped, nearly one-third of a mile across, and rises in its highest part 325 feet above the valley floor, with perpendicular cliffs 200 feet above its talus slopes. The tuff of which it is composed is a tawny, rather firmly cemented material, consisting of fragments of effusive rocks and volcanic cinder. This material is largely used in the western part of the county for building purposes, being soft when first quarried and easily cut into blocks that harden on exposure, and as it is used especially for chimneys it is locally known as "chimney rock."

A thick tuff bed also exists in the mountains south of Paisley and is well exposed in the Chewaucan River canyon a short distance above the town. This tuff, which is colored various shades of red and blue, has been mineralized to some extent by quartz and calcite. Toward its southern end considerable prospecting for gold has been done, and good values are reported to have been found in some places. The remains of an old arrastre, half a mile below these workings show that for a number of years the locality has been prospected for the precious metal.

Interbedded with the basalts are thinner layers of tuff, or volcanic mud and ash. These are usually rather fine grained, white or red in color, and contain fragments of basaltic rocks. Where exposed along cliffs these tuff beds thin out, as if lenticular in shape, and in some instances serve to accentuate any unevenness in the associated basalt beds.

These tuffs also exhibit interesting contact phenomena, as at North Alkali Valley, where a white tuff bed about 4 feet thick is exposed for several miles in the cliff along the eastern side of the valley. The contact with the underlying basalt is sharp and exhibits no alteration. From this line upward the color changes evenly through brown to black at the upper contact, where the tuff has been melted to a beady glass by the heat of the succeeding flow. This overlying rock is lighter colored and less dense than the usual basalt, and covers much of the area surrounding Alkali Lake basin, but it probably belongs to the same period of effusion as the more close-textured basalt to the south, into which it seems to grade.

RECENT ERUPTIVE MATERIAL.

In the northern part of the county is an area covered by sheets of lava and small volcanic cones or craters that represent a very recent period of volcanic eruption. Black vesicular basaltic rock constitutes the main part of the flow, while the cones are built up of slaglike fragments of scoria and volcanic bombs. This material clearly was ejected at a period much later than that of the great Miocene flows. It is probably Pleistocene in age.

VALLEY FILLINGS.

The loose Pleistocene filling of the valleys and the alluvial material brought down by streams may be considered as a fourth class of surface material in this region.

Lake deposits.—No marine beds were seen, but some lake deposits should be mentioned here. Along the hills east of Summer Lake, and fully 150 feet above its present level, there are beds aggregating 25 feet or more in thickness. These are composed of basaltic pebbles and shells of fresh-water mollusks, cemented into a conglomerate by lime carbonate.

Many of the stones around the borders of the lake basins are coated with a hard, white deposit of lime, in many cases half an inch thick. One mass of this material 10 or 15 feet in diameter, observed on the western edge of Summer Lake, is probably a tufa deposit of lime carbonate, such as Russell found so common along the shores of the ancient Lake Lahontan, in Nevada and California.

In all of the lake valleys there are deposits of silts, sands, and clays that form the floor of the valley and usually bury any coarser material that may be in the basin. Remains of Pleistocene mammals fix the age of these deposits at Fossil Lake, in Christmas Lake Valley, where somewhat extensive collections have been made by representatives of the Smithsonian Institution, and in 1904 by a party from the University of California.

Alluvium.—Some alluvium is to be found where the several streams debouch into the open valleys, but in few places is the area thus covered of great extent. Probably at the mouth of the Chewaucan River canyon there is the largest area of this stream-deposited material. Here the gravel-covered terraces at Paisley have clearly been built by the river, probably as a delta in the former lake, and the low divide between Summer Lake and Chewaucan Marsh is largely if not entirely formed of river wash.

Honey Creek, in Warner Valley, has also brought down and deposited on the valley edge a large amount of gravel.

Landslides and the slower weathering action that produces talus have also brought down much loose material from all the cliffs and steep slopes, but the areas covered by such material are not large.

Although in comparison with the great rocky basaltic areas these loose materials are geologically of minor importance, it is from them that practically all of the limited quantity of ground water now used is obtained. Hence from the view point of the present water resources in the region this fourth class of unconsolidated material is perhaps the most important. The cultivable land is also limited to these areas of lake and stream deposits, so that the possible agricultural portions of the county—neglecting alkaline conditions, which will be discussed in detail later—are shown on the geological map (Pl. VI) by the colors that represent these deposits.

STRUCTURE.

FAULTS.

Probably in but few other places in the world is the geologic structure so well exhibited in the present land forms as it is in southeastern Oregon. Here the main features of relief are a direct result of deformation of the rocks. This deformation has resulted in faults, which are the main structural features, as their expressions in scarps are the main topographic features.

In most of the Great Basin region the typical Basin Range structure, produced by the faulting and tilting of long, narrow orographic blocks, is largely obscured by erosion or by earlier complex structures. But in Lake County erosion has acted very little on these great blocks, and little or no deformation preceded the faulting, so that the typical structure is evident in the present conformation of the surface. The geologic cross section (see Pl. X) through Chewaucan Marsh, Lake Abert, and Warner Valley well exhibits this characteristic tilted block structure, and in Pl. VIII, reproduced from Russell's "Reconnaissance," the block between the marsh and Lake Abert is seen to be of this origin.

^a Russell, I. C., Geological reconnaissance in southern Oregon: Fourth Ann. Rept. U. S. Geol. Survey, 1884.

In a general way the southern country is more broken by faults than the northern. This fact is not as evident from the map (Pl. II) accompanying this report as it would be were more of the region to the east and north shown; still, it will be noticed that in the northern part of the area mapped prominent scarps are not in evidence, while they are in the southern portion.

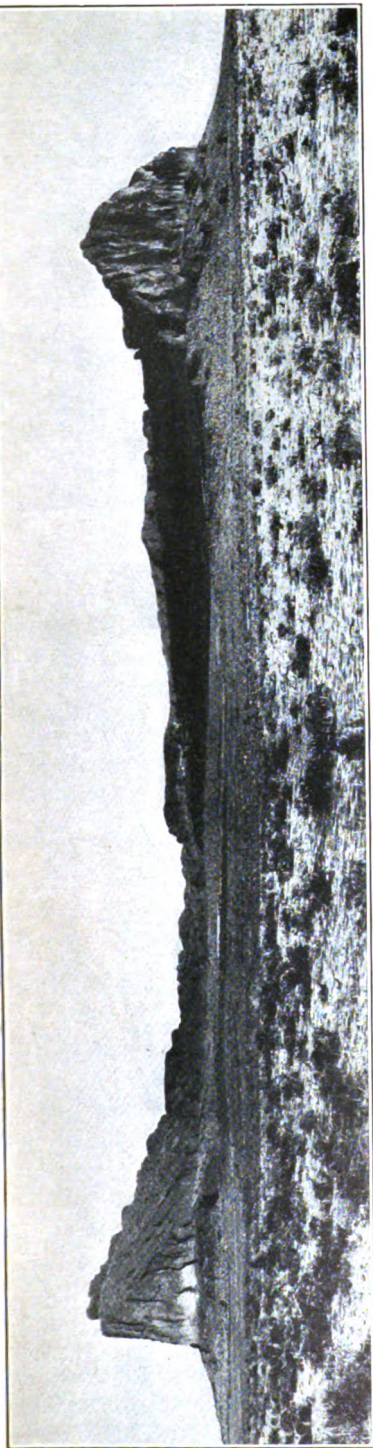
FOLDS.

Besides these tilted blocks there are low folds in the bedded lavas. In the production of these, however, the rock itself has been bent little if any. The very slight opening and closing of the multitude of approximately vertical fractures in the beds has been sufficient to allow the low folds to be formed. In Lake County the other structural features seem closely related to a great upward fold or anticline of this character, which has been extensively faulted in places; and the structure of the region has been tentatively worked out on this assumption, as follows:

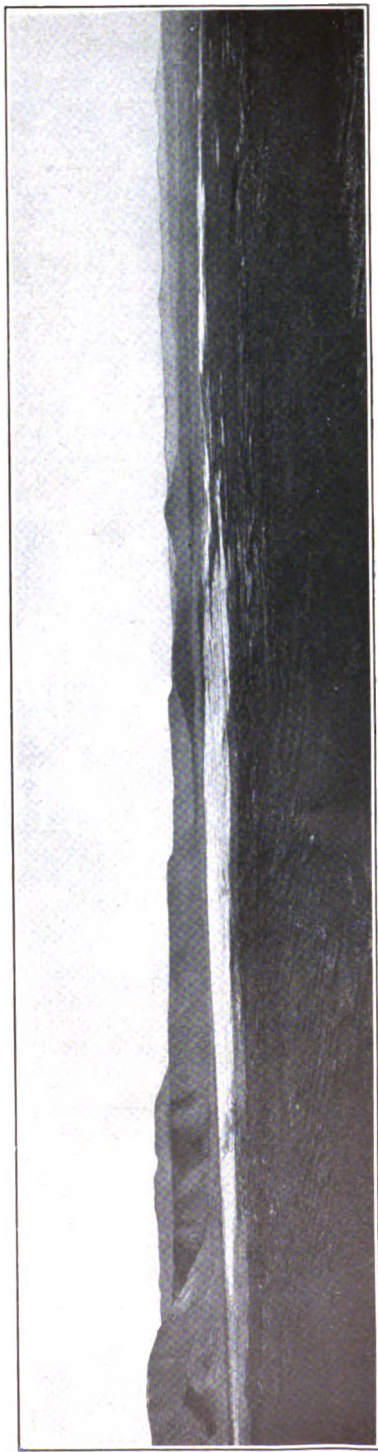
The axis of this major anticline extends from Silver Lake southward through Goose Lake Valley, approximately along the straight line A-A', Pl. VI. At its southern end the monoclinal slope at the western side of Goose Lake Valley and the steep slope at its eastern side suggest that here the anticline has broken down and that Goose Lake Valley lies, as it were, on the dropped keystone of an arch. (See section, Pl. X.) To the north dips in the beds indicate that Chewaucan River has cut its channel along the axis of the fold for a number of miles. Through Summer Lake Valley it appears that the anticline has again broken down, its western side remaining in place to form Winter Ridge, while the eastern is buried beneath the lake deposits. White Rock, a tuffaceous exposure in the bluff at the northwest side of the valley, seems closely to mark the northern point of this breaking down, for northward from it a very evident plunging anticline forms the slopes to Silver Lake. In the hills north of this lake the fold does not show.

The near parallelism of Elder Creek with the axis A-A' is also to be noted, and in a broader way the approximate parallelism of Chewaucan Marsh.

One of the areas examined in which the folds are irregular and complex in a minor way is that at the northern end of Summer Lake Valley. As indicated on the geologic map (Pl. VI), the dips of the beds on each side of Sheep Lick Draw show that a smaller fold, whose axis is B-B', exists here, which dies out toward the crest of the divide between Christmas Lake and Summer Lake valleys. This divide has the character of a cross anticline whose axis is C-C', and these three upward folds, together with the synclinal fold up whose trough



A. FORT ROCK, FROM THE SOUTHEAST.



B. ALKALI LAKE, FROM THE NORTH.

the county road between Summer Lake and Silver Lake passes, have produced a peculiarly warped surface.

In the southeastern part of the area studied the plateau between Goose Lake and Warner Lake valleys has the character of a wide, low syncline, while the dips on each side of southern Warner Valley indicate that, like Goose Lake Valley, it has been formed by the faulting of an anticline, as shown in the section through south Warner Valley (Pl. X). At its northern end the dips indicate more purely monoclinical faulting, as shown in the section through Chewaucan Marsh (Pl. X).

Over all of the northeastern part of the county the beds lie approximately horizontal, indicating, as before stated, that there has been less deformation in that region. Even at a short distance from the base of Wagontire Mountain the surface beds are nearly level.

There are many minor scarps, especially in the broken country northeast of Summer Lake and at the south end of Silver Lake. These, however, do not seem to be of fault origin, but are apparently weathering rather than structural features.

As in the topography the scarps were shown to be the main features, so the faults producing these scarps and their associated undrained basins are again emphasized as being the chief structural features. In this respect the low folds are treated as of secondary importance; for although, as tentatively shown, the structure has been determined largely by a great anticline which has collapsed in places, the most striking features along this fold are the results of faulting.

PHYSIOGRAPHY.

EARLY HISTORY.

In attempting to trace the development of the present topographic features of Lake County and vicinity it must first be considered at the period immediately following the outpouring of the great basaltic lava floods of Miocene time. Only the very scantiest and most fragmental evidence exists for deciphering the history of the region before this period, but data for unraveling the later evolution of the land forms are much more abundant.

At the close of the great lava outflow Lake County and the adjacent regions north and east probably formed one widely extended plateau, above which projected, like islands in the basaltic inundation, only isolated peaks of the former surface, such as Big Juniper and Little Juniper mountains, Gray Butte, and the Coyote Hills. There could have been little topographic diversity in the entire region, for the prominences mentioned were but minor elevations, widely scattered, and rising but little above the general broad levels.

Drainage could not have been definite or well developed; indeed, if precipitation was as light then as it is at present, there were probably few streams in existence.

DEFORMATION.

Some time after this broad constructional plateau came into existence, at a time which can not be fixed definitely on the basis of any evidence gathered within Lake County, but which, to judge from similar events whose history has been more closely traced farther to the north and to the south, was in the Pliocene epoch, earth movements began that resulted eventually in the uplifting of the Cascade Range in the north and of the Sierras in the south. Although the locus of these movements, or the line of their greatest intensity, lay well to the west of the area under discussion, this area was itself markedly affected by them. The movements, whose axis of greatest intensity coincided roughly with the present crest of the Cascade Range, exhibited as they passed eastward a constantly diminishing intensity, so that here, while great mountain ranges did not come into existence as one of their products, the old plateau, which had existed before the disturbance, was extensively modified. This modification in various parts of the piedmont area at the eastern base of the Cascades took the form in some localities of low folds and resulting ridges, in others of faults of limited throw with a resulting appropriate topography, and in still others of a combination of faults and folds. Whatever form the movement took, it produced a marked change in the preexisting land forms.

In Lake County faulting seems to have been the dominant expression of this movement, although folding also took place. The great scarps which are so characteristic of the region and which limit practically all of its major depressions on one or the other side date from this period and are themselves due directly to the breaking of the lava beds, their broken edges now constituting the scarps in question.

The preexisting plateau was broken by these movements into a series of irregular blocks, some of which were dropped bodily and are limited by faults on either side, while others are tilted to the east or the west, giving structures that, since the work of Gilbert and Russell, have come to be known as Basin Range structures. In other parts of the area, especially farther north, where the movements seem to have been less intense or less definitely localized, broad ridges were raised without fracturing. Such a ridge is that which extends north of east from the vicinity of Squaw Peak through St. Patricks Mountain. This ridge separates Silver and Summer lakes, where it is clearly anticlinal in character, but eastward from this area it gradually dies out or becomes less definite as a structural feature.

PRESERVATION OF DEFORMATIONAL FEATURES.

The topographic forms that resulted from this series of general crustal movements seem to have been preserved with comparatively little modification to the present day, and from this fact it appears that, though the region is one of light rainfall, so that the usual erosional forces operate with comparatively slight intensity, the movement must have been relatively recent. For had these forms existed for any extended time, even under desert conditions of minimum precipitation and minimum stream development, they would have been considerably modified. The greater scarps, like those which limit on the east the valleys in which lie Goose, Abert, and Alkali lakes, are comparatively unmodified. This is equally true of the scarps that confine the Warner Lakes on the east and of the somewhat less pronounced scarps that limit them on the west. Winter Ridge, to the west of Summer Lake, although it has been slightly modified by landslides since it came into existence, exhibits substantially its original form. The greatest evidence of the action of erosion or disintegration is found in a few localities like that at the south end of Silver Lake. Here exists a valley whose extension is occupied by Silver Lake, and scarps have been formed limiting this valley on both the east and the west that can not be accounted for as fault features, because Silver Lake and its valley seem to occupy the axis of an unbroken anticline. Rocks along its crest were presumably weakened and therefore easily subject to attack by disintegrating agents, and perhaps on this account these agents have been most effective here.

Over large areas in the northern part of the county, areas that are now known generally as the "high desert," the effect of the crustal movement that elsewhere produced the scarps and the valleys that accompany them seems to have been merely to warp slightly the original constructional plateau, so that it is now a high, rolling, irregular plain, changed scarcely at all from its original condition. Similarly the surfaces of some of the blocks whose edges form the conspicuous scarps—surfaces like that of the great ridge that separates Abert Lake and Warner Lake valleys—exhibit little change, other than the tilting they have suffered, from the original surface of the plateau from which they are derived. It is probable, indeed, that portions of these surfaces coincide with the surface that existed before deformation had affected the region at all. The faulting and folding, in other words, have deformed the surfaces as well as the rocks, and these deformed surfaces are the present topographic features of Lake and adjacent counties.

EROSIONAL MODIFICATIONS.

Where streams like Chewaucan River drain higher ridges in the western portion of the county—ridges that because of their great

height have a greater rainfall and consequently a greater run-off—gorges due to erosion have been formed, and other modifications of the original deformational surface are found. These modifications are usually greatest where the rocks were made more vulnerable to attack by erosional agents through weakening along fault lines or upturning along folds. At such places sharp canyons have developed that follow strike lines closely and have been cut out along weak zones in the disturbed rocks. But except near the western edge of the county, where these favoring conditions of high rainfall, sharp relief, and weakened rocks have combined to yield limited areas of topographic forms that are erosional instead of constructional, the surface of the county is almost exclusively dependent upon constructional forces.

LAKES.

Present lakes.—As an immediate result of the movements by which the ridges with their limiting escarpments and the valleys that lie at the bases of these escarpments were formed, the lakes that dot the surface of the county and give it its name came into existence at the lowest points of the deformed surface, from the accumulation there of such slight run-off as the meager rainfall of the region furnished. Each constructional basin has its own drainage, and the drainage accumulates at the lowest point within the basin. If it is more than sufficient to satisfy evaporation, a lake exists in the depression; if evaporation is as effective in removing the water as rainfall is in supplying it, playas or intermittent lakes, like Alkali Lake, result.

Quaternary lakes.—During Quaternary time the basins of Lake County contained much greater bodies of water than at present. These have left evidences of their former extent in the terraces or ancient shore lines cut in the surrounding hills, in the lake deposits, and, as at Paisley, in the formation of deltas rather than of alluvial fans opposite canyon mouths. At Willow Ranch, south of New Pine Creek; shells of fresh-water mollusks are said to be found 150 feet above the present lake surface. On the eastern side of Summer Lake Valley similar shells are found, and faint terraces along Chewaucan Marsh show that Lake Abert, the marsh, and Summer Lake were once continuous. According to Russell,^a the water once stood 260 feet deep over the marsh and 300 feet deep in Summer Lake Valley. Silver Lake and Christmas Lake valleys once formed a wide, continuous, rather shallow expanse of water; but the present small bodies are not to be considered as remnants of this former lake.

The most distinct terraces in the region are to be found in the hills surrounding the Alkali Lake basin. Several deeply cut notches in these hills show successive stages of the lake level, the highest being

^a Russell, I. C., A geological reconnaissance in southern Oregon: Fourth Ann. Rept. U. S. Geol. Survey, 1884, p. 459.

275 feet above the present flat. The approximate extent of these Quaternary lakes is indicated by the areas of alluvium shown on Pl. VI.

HYDROGRAPHY.

STREAMS.

From the nature of the topography of this region, the area draining into each lake basin is rather limited, and the amount and character of the discharge depend almost wholly on local precipitation.

ABERT LAKE DRAINAGE.

Chewaucan River and its branches above Paisley form the largest drainage system in the county, with an area of about 272 square miles. Nearly all of this is in the higher, timbered region, where conditions are favorable for heavier precipitation and for the conservation of the rainfall and snowfall, hence the stream flows in good volume throughout the year. Near Paisley its canyon opens rather abruptly into the lake valley, and after flowing beyond its former delta deposit the water, except where carried off through drainage canals, sinks in Chewaucan Marsh. At the lower end of the marsh the water again rises, and after dropping over a low basaltic ledge empties into Lake Abert.

Several other smaller streams east of the upper portion of the Chewaucan basin carry northward much water from the mountains and join Chewaucan River before it reaches Lake Abert. Moss, Coyote, and Crooked creeks are the largest of these. Moss Creek, with from 30 to 40 miner's inches summer flow, drains only a small area, but its source in springs in the timbered mountains insures it a fairly reliable discharge. Near its entrance into the lower Chewaucan Valley part of the water is diverted to irrigate alfalfa and vegetables. Coyote Creek flows through a small open valley in the portion of its course between the mountain slopes and the gorge that carries it toward Lake Abert, but during the late summer a great part of its water sinks before reaching Chewaucan River. Crooked Creek in its course through its upper valley has cut a channel in the alluvial filling 20 feet or more deep, with vertical banks, and in its lower stretches it is confined in a narrow canyon until it reaches the more open valley a few miles south of Lake Abert. It unites with Chewaucan River just before the latter enters the lake.

SILVER LAKE DRAINAGE.

The drainage basin of Silver Creek is also mostly a timbered area, the stream being fed mainly by waters from the slopes south and southwest of Hager Mountain. Together with Bridge Creek and

Bear Creek (locally known also as Buck Creek), two streams that drain the slopes farther to the west, it supplies Silver Lake. Like Chewaucan River, these streams sink in Pauline Marsh, and through it the water reaches Silver Lake.

SPRAGUE RIVER DRAINAGE.

The western edge of the county is drained either by Sprague River and its branches directly or through Sycan Marsh into this stream, whose waters finally discharge into Klamath Lake. This area is also mountainous and wooded, but drains westward, away from the region with which this paper is concerned.

GOOSE LAKE DRAINAGE.

A number of small streams flow into Goose Lake, the chief of these in Oregon being Drews and Cottonwood creeks. These have their sources in the wooded slopes of the northwestern side of the valley, but their waters generally sink in the lowlands before reaching the lake. Bullard Creek, near Lakeview, and Kelly Creek, near the town of New Pine Creek, are but small mountain streams, while in California a number of similar small intermittent streams carry the run-off from the sides of the narrow basin to the lake. A very low divide separates the south end of the lake from the north fork of Pit River, into which it has been known to overflow. The present lake surface is about 190 square miles in area, about 60 square miles of which is in Oregon.

SUMMER LAKE BASIN.

Summer Lake, about 70 square miles in area, is largely independent of local run-off for its supply, for Ana River, its principal feeder, has its source in at least five large springs that rise in the sediments at the north end of the valley. The total flow of these springs is very constant, being, as measured by Mr. I. Landes, of the Reclamation Service, 148 to 150 second-feet, or 7,400 to 7,500 California miner's inches of 9 gallons a minute. Even during the dry season of 1887-8 it is said not to have decreased noticeably. Buckhorn and Johnson creeks have like sources in the sediments of the north end of the valley, but their waters sink before reaching the lake. Along the western side of the valley numerous streams rising in the slopes above flow into the lake, but the total discharge of the sixteen that were flowing measurably in September, 1906, was only 250 to 300 miner's inches, or about 4 per cent of that of Ana River.

WARNER VALLEY STREAMS.

Into Warner Valley only three streams of any consequence flow. Honey Creek enters the valley at its western edge, near Plush; Warner Creek also enters from the west, at Adel, while Twelvemile Creek

flows into the south end of the valley at Warner Lake post-office. These are perennial streams, but they have only a small discharge, hardly sufficient to balance evaporation from the lake, which is now broken into several detached water bodies.

NORTHERN DESERT AREA.

In Christmas Lake Valley there are no perennial streams. Peter Creek, in the northern arm of this valley, is the nearest approach to a living stream, but even in the spring it often flows no farther south than its sink. Lost Creek is the largest stream in the northeastern part of the area visited, having a discharge of 10 to 15 inches in the fall of 1906. Northward it flows only to a playa near the base of North Glass Butte.

Three or four ranches have been taken up along the eastern side of Wagontire Mountain, where springs issue. Of these springs the largest is that at Antone Egli's, the water of which is used for irrigating alfalfa. Its flow in November, 1906, was 8 or 9 miner's inches. As this water has the highest electrical resistance of all of those tested, a sample of it was taken for analysis, the result of which is given on page 72 (sample B). The total solid content of only about 10 parts in 100,000, or 5.84 grains to the gallon, shows it to be a very pure water.

DISCHARGE MEASUREMENTS.

During the last two years gaging stations have been kept by the United States Geological Survey on several of the streams of the county, the estimated discharges of which are given below.

Estimated monthly discharge of Chewaucan River at Paisley,^a Oreg., in 1905 and 1906.

Month.	1905. ^b				1906. ^c			
	Discharge in second-feet.			Total in acre-feet.	Discharge in second-feet.			Total in acre-feet
	Maximum.	Minimum.	Mean.		Maximum.	Minimum.	Mean.	
January.....	332	53	94.1	5,786	111	46	65.9	4,050
February.....	111	23	64.6	3,588	111	46	62.6	3,480
March.....	223	64	136.0	8,362	739	68	173.0	10,600
April.....	318	131	230.0	13,690	837	211	563.0	33,500
May.....	290	198	238.0	14,630	1,000	387	670.0	41,200
June.....	318	53	154.0	9,164	649	259	415.0	24,700
July.....	64	23	33.2	2,041	234	37	110.0	6,760
August.....	23	19	19.5	1,199	37	29	30.5	1,870
September.....	36	19	23.5	1,398	68	29	37.9	2,260
October.....	36	23	28.5	1,752	46	29	37.3	2,290
November.....	36	23	29.7	1,767	68	37	47.8	2,840
December.....	223	23	70.8	4,353	81	23	52.1	3,200
The year d.	332	19	93.5	67,730	1,000	23	189	136,750

^a Gaging station established January 4, 1905. I. Landes, hydrographer.

^b Report of Progress of Stream Measurements for 1905. Water-Supply Paper No. 176, U. S. Geol. Survey, p. 135.

^c From unpublished records of United States Geological Survey furnished by J. C. Stevens, district hydrographer, Portland, Oreg.

^d Ice gorge January 10-31; discharge, assumed 77 second-feet. Ice conditions for remainder of winter months not known; open channel rating table applied.

Estimated monthly discharge of Silver Creek near Silver Lake,^a Oreg., in 1905 and 1906.

Month.	1905. ^b				1906. ^c			
	Discharge in second-feet.			Total in acre-feet.	Discharge in second-feet.			Total in acre-feet.
	Maximum.	Minimum.	Mean.		Maximum.	Minimum.	Mean.	
January.....	70	24	36.8	2,263	50	80	24.1	1,480
February.....	137	21	43.9	2,438	78	7	27.6	1,530
March.....	155	54	73.9	4,544	212	10	40.4	2,480
April.....	203	46	89.9	5,349	530	57	320	19,000
May.....	87	27	47.2	2,902	246	43	118	7,260
June.....	39	21	27.8	1,654	106	21	45.7	2,720
July.....	21	13	16.7	1,027	86	12	31.3	1,920
August.....	19	15	17.1	1,051	15	12	12.5	769
September.....	19	15	15.4	916	15	12	12.9	768
October.....	21	15	15.7	965	13	12	12.0	738
November.....	42	13	21.4	1,273	5	5	12.7	756
December.....	36	13	21.6	1,328	31	5	13.5	830
The year d.	203	13	35.6	25,710	530	5	55.7	40,251

^a Station established December 29, 1904. I. Landes, hydrographer.

^b From Water-Supply Paper No. 176, U. S. Geol. Survey, p. 129.

^c From unpublished records of United States Geological Survey, furnished by J. C. Stevens, district hydrographer, Portland, Oreg.

^d Ice is known to form at this station during winter months, but the observer failed to note the length of time that ice conditions existed during 1905. The open channel rating table was applied to the winter months without correction.

Estimated monthly discharge of Bridge Creek near Silver Lake,^a Oreg., in 1905 and 1906.

Month.	1905. ^b				Month.	1906. ^c			
	Discharge in second-feet.			Total in acre-feet.		Discharge in second-feet.			Total in acre-feet.
	Maxi- mum.	Mini- mum.	Mean.			Maxi- mum.	Mini- mum.	Mean.	
January 21-31..	8.1	2.0	4.55	99	January.....	21	11	16.6	1,020
February 1-19, 24-28.....	10.0	1.2	4.33	206	February.....	21	11	17.1	950
March.....	2.8	1.2	2.23	137	March.....	14	4	10.4	640
April.....	6.6	.8	2.53	151	April.....	23	7	10.5	625
May.....	12.9	1.3	7.79	479	May.....	29	14	21.1	1,300
June.....	15.2	3.0	10.6	631	June.....	22	15	18.7	1,110
July 1-6.....	3.0	.6	2.18	26	July 1-21.....	25	6		
August 7-31....	.8	.2	.46	23					
September.....	.7	.6	.66	39					
October.....	.9	.6	.73	45					
November.....	1.5	.7	.95	57					
December d.....	1.3	.2	1.00	61					

^a Station established January 21, 1905. I. Landes, hydrographer.

^b From Water-Supply Paper No. 176, U. S. Geol. Survey, p. 131.

^c From unpublished records of United States Geological Survey, furnished by J. C. Stevens, district hydrographer, Portland, Oreg.

^d Ice conditions December 17-31; discharge estimated, 1.3 second-feet.

Discharge measurements of Bear Creek near Silver Lake,^a Oreg., in 1905.^b

January 24.....	14.4	August 7 f.....	6.3
February 23 c.....	23.6	October 4.....	5.0
March 17 d.....	11.7	October 24.....	6.4
May 31 e.....	50.0	November 11.....	6.8
June 15.....	46.0		

^a Station established January 21, 1905, at County Bridge. I. Landes, hydrographer. Results for 1906 unsatisfactory, and station discontinued.

^b From Water-Supply Paper No. 176, U. S. Geol. Survey, p. 131.

^c 500 feet below bridge.

^d 400 feet below bridge.

^e 100 feet above bridge.

^f 300 feet below bridge.

Approximate annual discharge of the several streams of Lake County, Oreg., in 1905 and 1906.

Stream.	Approximate area of drainage basin in square miles.	1905.		1906.	
		Discharge for year in acre-feet.	Run-off in inches (to nearest tenth).	Discharge for year in acre-feet.	Run-off in inches (to nearest tenth).
Chewaucan River.....	272	a 67,730	4.7	a 136,750	9.4
Silver Creek.....	221	a 25,710	2.2	a 40,251	3.4
Bridge Creek.....	45	b 2,100	.9	b 6,660	2.8
Bear Creek.....	62	b 12,600	3.8	c 18,500	5.6
Crooked Creek.....	95	c 12,000	2.4	c 17,750	3.5
Coyote Creek.....	47	c 2,000	.8	c 3,300	1.3
Moss Creek.....	16	c 1,500	1.8	c 2,200	2.6

a From measurements of United States Geological Survey.

b By interpolation in the incomplete records of the United States Geological Survey.

c Estimated by comparison with discharges of Silver and Bridge creeks.

CHARACTER OF DISCHARGE.

In the monthly stream-discharge tables a fact worthy of mention may be noted. The time of greatest discharge of Chewaucan River is during April and May, its maximum being reached in the latter month. Silver Creek, being smaller and draining less mountainous country, would be expected to reach its maximum flow somewhat earlier, as it does, in April. But Bridge Creek, with a drainage basin of only 45 square miles, does not reach its highest period until May or June. This is probably to be accounted for by the fact that its supply comes chiefly from the north slope of Yamsay Mountain, where melting of the snow is slower than on the eastern slopes drained by Silver Creek.

Another peculiarity, not explainable from the data at hand, concerning Bridge Creek is that, although judging from the records kept at Lakeview and Silverlake the precipitation was only about 50 per cent more in 1906 than in 1905, the total discharge of this stream, as shown by the figures of approximate discharge given above, was more than three times as great, so that the ratio of run-off to precipitation within its basin about doubled. For the other streams the discharge during 1906 was, like the precipitation, roughly 50 per cent greater than that of 1905, so that the run-off ratio remained about the same during these two years.

RUN-OFF RATIOS.

Much study has been given to the relation of rainfall to run-off, and attempts have been made to deduce formulas for determining their ratios in different regions. So many complex conditions influence the run-off, such as amount, intensity, and distribution of rainfall, nature of soil, slope of surface, area and configuration of basin, as well as

geologic structure, forest, wind, etc., that the ratio can be stated only in a very general way.^a

Newell^b gives general curves showing the ratio, and they indicate that for a region like southern Oregon, in which the precipitation in the higher drainage basins is probably from 15 to 20 inches, the run-off is usually between 3 and 5 inches.

The amount of run-off deduced in the table on page 35 from the estimates of approximate discharge departs from these figures in several cases, but in those records that are considered the most reliable the run-off agrees fairly well with this general ratio of one-fifth to one-fourth.

Since no records of precipitation have been kept on the higher areas, the apparent departures from this ratio may fairly be assumed to be due, in part at least, to uneven distribution of the snowfall within the several drainage basins.

EFFECT OF FORESTS.

Because rainfall is most abundant in forested regions many believe that forests exert an influence favorable to precipitation. While they may have an appreciable cooling effect on the air, aiding to reduce the temperature below the dew point and thus to produce rain, the evidence on this matter is so conflicting that definite conclusions can not yet be reached. It seems more reasonable, however, to believe that abundant rainfall is the great factor in controlling the distribution and density of forests, rather than that the forests cause greater rainfall.

Although the relation of forests to rainfall and run-off is a complex problem, into which enter the factors of climate, topography, geography, and geology, there is no doubt whatever that the forests store a part of the rainfall in their spongy soil and loam, whence it enters the streams gradually rather than suddenly, and that they protect the accumulations of snow from rapid melting and evaporation; therefore the preservation of the forests is of vital importance.

A large part of the precipitation on all areas is returned to the air by evaporation. From the tree crowns immediately after a storm this return is, of course, very rapid, but the amount thus evaporated is only a small fraction of the total precipitation. From the forest-covered soil evaporation is comparatively slow, because the soil is protected from sun and wind, and the amount of moisture absorbed by a forest to supply the plant needs is probably less than that needed by the average agricultural crop. The total quantity annually returned to

^a Rafter, George W., Relation of rainfall to run-off: Water-Supply Paper No. 80, U. S. Geol. Survey, 1903, p. 9.

^b Newell, F. H., Results of stream measurements: Fourteenth Ann. Rept. U. S. Geol. Survey, pt. 4, 1894, p. 151.

the atmosphere from a forest by transpiration through the stems and leaves and by evaporation from the trunks and from the soil has been estimated at 75 per cent of the precipitation, while for fields of cereals and grasses it may be even more, in regions where from a bare field the evaporation may be only 30 per cent of the precipitation.^a But the amount of moisture annually evaporated from forest-covered soils and transpired by the trees themselves is only about half as great as that from open fields having a moderate covering of herbage.^b

On the other hand, in regions of scanty rainfall, where a short wet season is followed by a long dry one, evaporation from the forest soil may go on slowly throughout nearly the whole year, while in the open, during a great part of the year, there is very little moisture to be evaporated and therefore little loss by transpiration from the scanty herbage, so that in such a case the forest-covered soil may lose more moisture by evaporation and transpiration than the open field. The spongy forest soil also, by retaining a large part of the scanty rainfall, lessens the stream flow from such an area. This is notably the case in many parts of the arid West.

The greatest collateral usefulness of a forest, however, lies in its power to regulate the run-off and to maintain a more equable flow of the streams. This it does by decreasing the surface run-off of flood waters and by increasing the seepage run-off from the saturated soil, which is the water that sustains stream flow. This is of far greater benefit than would be the extra water carried off by streams to the valleys below if the slopes were cleared. Indeed, usually the greater run-off of cleared areas is in the form of violent and destructive floods. A regulated flow, even though the total discharge may be less than the sum of a succession of floods, is vastly more beneficial, for "It is the amount of water that passes into the soil, not the amount of rainfall, that makes a region garden or desert."^c

Minor but important effects of forests are protection from wind erosion as well as from erosion by water, prevention of snow slides in some localities, moderation of extremes of temperature, and, perhaps, distribution, if not increase, of precipitation.

LAKES.

CHANGES IN SURFACE LEVEL.

On account of the shallowness of the water bodies of Lake County the water level of the lakes can fall but little without destroying them. Such occasional dryings up have no doubt occurred within recent times. The best-known instance is that of Silver Lake. In

^a Fernow, B. E., *Economics of Forestry*, New York, T. Y. Crowell & Co., 1902, p. 438.

^b *Ibid.*, p. 437.

^c Toumey, James W., *The relation of forests to stream flow*: Yearbook U. S. Dept. Agriculture for 1903, p. 288.

1879 Cope found Thorn Lake dry and Silver Lake low, but Russell states that during the following three years the surface of Silver Lake rose 6 feet and in 1882 was confluent with that of Thorn Lake. As has been stated, in 1888-89 Silver Lake completely dried up, which required a change in level during these six or seven years of at least 10 feet, for Russell stated that in June, 1882, when confluent with Thorn Lake, it was only 10 feet deep. In 1890 it again began to fill, and during the fall of 1906 the gage board established by the Reclamation Service indicated about 13 feet, but it was not learned whether this was supposed to be the depth of the lake.

It is claimed that Thorn Lake is supplied only by precipitation and occasional overflow from Silver Lake. As such overflow does not take place every year, evaporation would more than counterbalance these two sources of supply, and it therefore seems probable that it is fed by springs beneath its surface, like those at Christmas and Fossil lakes. The effect of the dry season of 1887-88 on all of the lakes would be useful for comparison, but it is not known; it was only learned through hearsay that Summer Lake shrank little, if at all.

Noted changes in the level of Summer Lake are not recorded, but from the nature of the alkaline wastes along its eastern side it would appear that it is slowly shrinking.

The northern end of the Abert Lake basin is so nearly level that it is said that a strong south wind often forces the water back nearly 2 miles over the alkaline flat; so it seems very probable that seasonal changes shift the northern margin considerably.

Goose Lake experiences differences in its level, but fluctuates more slowly than the smaller lakes. The story that in the early sixties an emigrant trail crossed its valley at a place where the water is now several feet deep indicates that the lake was then smaller than at present, but a few years later it rose so as to extend several miles farther north than it now extends, and for a short time (in 1869) it overflowed southward down Pit River. Since then it has shrunk, and is apparently still growing smaller.

The litigation in Warner Valley strongly emphasizes the fact that this lake has been shrinking since 1860, but at what rate can not be said, as there are no recorded observations and seasonal differences obscure the slower general change.

The Alkali Lake drainage basin has an area of about 300 square miles, but it is all desert; no perennial streams exist in it, and consequently the depression, except for a few pools, is dry during a large part of the year.

ANNUAL SURFACE INFLOW.

With the meager discharge measurements given on pages 33-34 as a basis, the mean annual flow into each of the lakes has been estimated as well as may be, and comparison of inflow with drainage area and

lake surface has led to some interesting conclusions. The areas of the drainage basins and of the lake surfaces can be obtained approximately from the map (Pl. II). Aside from the discharge tables given, data for estimating the inflow to the several lakes are lacking; but by comparing the observed width, depth, and velocity of other streams with the measured ones, a rough estimate of the stream discharge into each basin has been made and the following tables have been prepared.

The average rainfall records of 16.73 to 17 inches at Lakeview and 10.06 to 10.4 inches at Silver Lake given on pages 15-16, are for periods of twenty-two years at Lakeview and thirteen years at Silver Lake; and it has been estimated^a that averages based on such lengths of time may differ from the final average by only about 3 per cent and 5 per cent respectively.

The stream-gaging record for 1905 is that for a year of 9.92 inches precipitation at Lakeview and 7.78 (?) inches at Silver Lake, or only about two-thirds of the average; but for 1906 the precipitation was 19.24 inches at Lakeview and 11.58 inches at Silver Lake, figures not greatly exceeding the average. So for the purpose of estimating the flow into each lake, the observed and estimated discharge records for 1906 have been used, since they are probably as close to the average as can be approximated.

From the average precipitation records an annual total of 14 inches upon the open surface of Goose Lake has been thought reasonable, while 12 inches has been assumed as the average annual precipitation upon the surfaces of the lower lakes—Summer, Silver, and Abert.

All of the following estimates are necessarily very general, being based on general data; still, for the facts they are meant to indicate, it is thought that the figures given are sufficiently accurate.

The annual surface flow into the several lakes was computed from the following estimated stream discharges, which were based on the character and size of the drainage areas of the several streams, as compared with the streams whose discharges have been measured.

Annual discharge of streams flowing into Goose Lake.

	Acres-feet.
Cottonwood Creek.....	6,000
Drews Creek.....	18,000
Dry Creek.....	1,000
Stream in Warner Canyon.....	2,000
Bullard Creek.....	1,000
Kelly Creek.....	2,000
Sixteen streams in California with aggregate drainage area of about 250 square miles (taken from Alturas sheet of U. S. Topographic Atlas).....	30,000
	60,000

^a Rafter, George W., Relation of rainfall to run-off: Water-Supply Paper No. 80, U. S. Geol. Survey, 1903. p. 18.

Annual discharge of streams flowing into Abert Lake.

	Acre-feet.
Chewaucan River (measurement).....	136, 750
Crooked Creek.....	17, 750
Coyote Creek.....	3, 300
Moss Creek.....	2, 200
	160, 000

Annual discharge of streams flowing into Summer Lake.

	Acre-feet.
Ana River (150 sec.-ft., measurement).....	109, 500
Johnson Creek (20 sec.-ft.).....	14, 600
Total of other streams (10 sec.-ft.), partial measurement.....	7, 300
	131, 400

Annual discharge of streams flowing into Silver Lake.

	Acre-feet.
Silver Creek (measurement).....	40, 250
Bridge Creek (partial measurement).....	6, 650
Bear Creek (partial measurement).....	18, 500
	65, 400

As before stated, the annual precipitation on the surface of Goose Lake was taken as 14 inches; on the surface of the other lakes, 12 inches.

EVAPORATION RATES.

In the following table it is shown that the ratios of the area of each lake surface to its drainage basin differ greatly, and that the annual increment, expressed in feet of water on its surface, is also apparently very different for the several lakes. On the assumption that evaporation balances the inflow, the increment also represents the annual evaporation rate.

Areas of lakes and lake basins, and annual surface supply.

Lake.	Area of lake surface in square miles. ^a	Area of drainage basin (including lake) in square miles. ^a	Ratio of lake surface to entire drainage basin.	Annual surface inflow plus direct precipitation into lake, in acre-feet.	Annual increment expressed as feet in depth over the lake surface. ^b
Goose.....	190	1, 065	0.18($\frac{1}{5}$)	60, 000 142, 000 202, 000	1.66
Abert.....	60	900	.07($\frac{1}{14}$)	160, 000 38, 400 198, 400	5.17
Summer.....	70	550	.13($\frac{1}{8}$)	131, 400 44, 800 176, 200	3.94
Silver.....	15	500	.03($\frac{1}{33}$)	65, 400 9, 600 75, 000	7.81

^a Taken from map by measurement with planimeter.

^b Inflow plus direct precipitation (in acre-feet), divided by area of lake, in acres.

Evaporation experiments covering a period of five years at Fort Douglas, Utah, determined the yearly evaporation there as being 42.46 inches. As computed by the Signal Service, the rate at that place is 74.4 inches.^a

From a series of observations upon the rate of lowering of the level of Crater Lake, and from experiments to determine the rate of evaporation from its surface, Diller^b concluded that, allowing for escape by seepage, the average rate was about 53 inches annually, the surface reaching its highest level early in May and its lowest turning point about the 1st of October. Gannett some years earlier placed the rate of evaporation from this lake at 40 to 50 inches. Crater Lake is in nearly the same latitude as the water bodies of Lake County, but is 1,600 to 1,900 feet higher, and by virtue of the lower temperature of the surrounding air and because of its protecting walls, presumably is not subject to so rapid evaporation. Recent evaporation experiments at Keno, near Klamath Lake, Oregon, indicate an evaporation rate of about 40 inches annually at that place.^c

Other evaporation data for comparison are very meager, but it seems that from the water bodies of Lake County the rate is probably somewhat greater than from Crater Lake, or than at Keno, which is more closely surrounded by forested mountains than are the water bodies of Lake County.

In estimating the increment to the four lakes considered, and hence the approximate annual evaporation from their surfaces, no account could be taken of escape by percolation or leakage from their basins, for there was nothing to indicate the amount thus lost, if any at all; neither could an estimate be made of the amount evaporated from the marshes. Leakage may perhaps account in part for the large apparent increment of 7.8 feet to so small a water surface as that of Silver Lake, and also for the fact that this lake dried up so quickly after the dry season of 1887-88. Evaporation from Pauline Marsh also no doubt materially lessens the apparent increment to this lake, a part of the stream discharge being evaporated before reaching the lake.

From Chewaucan Marsh there is also probably much evaporation, so that Lake Abert does not receive so great an increment as is credited to it.

Summer Lake, with the great springs of Ana River pouring into it, has an apparent increment of about 4 feet. The existence of the

^aNewell, F. H., Results of stream measurements: Fourteenth Ann. Rept. U. S. Geol. Survey, 1894, p. 154. The results of experiments at Fort Bliss, Tex., given with those of Fort Douglas, are not quoted here, as they are for a region of higher mean temperature than that of southeastern Oregon.

^bDiller, J. S., and Patton, H. B., Geology and petrography of Crater Lake National Park: Prof. Paper No. 3, U. S. Geol. Survey, 1902, p. 61.

^cClapp, W. B., and Hoyt, J. C., Progress of stream measurements for 1905: Water-Supply Paper No. 177, U. S. Geol. Survey, 1906, p. 242.

great springs feeding it renders very plausible the theory that other springs than those known discharge into this basin. The marshy nature of Thousand Spring Valley, however, indicates that this concealed supply may be by seepage over a considerable area, rather than by concentrated flowing springs. This assumption is strengthened by the fact that, according to notes of the Reclamation Service, on August 17, 1904, the discharge of Ana River near its source was only 155 second-feet, while near its mouth the discharge was 179 second-feet, indicating the accession to it of seepage waters or waters from other springs.

Rate of evaporation is a subject comparatively little studied as yet; results of experiments are meager, and the methods employed are unsatisfactory. Observations on the rate from pans or from inclosed basins usually give figures too large. It seems, however, that the rate from the water bodies of Lake County is probably greater than that observed at Keno—about 40 inches, and possibly more than 53 inches, the rate given by Diller for Crater Lake; but in the following discussion the conservative estimate of 40 inches will be taken.

SUBSURFACE INFLOW TO GOOSE LAKE.

Goose Lake, it will be noticed from the table on page 40, occupies one-fifth of its entire drainage basin. A glance at the index map (Pl. I), on which the limits of the several lake basins under discussion are shown by dotted lines, will emphasize the disproportionate area of Goose Lake with respect to its drainage basin, as compared with the other lakes. Its estimated supply or increment is only 1.66 feet (19.92 inches) annually, and the consequent evaporation rate is seemingly a little less than one-half of that assumed, which is almost certainly not the case. Neither leakage from the basin nor evaporation from the marsh land near Lakeview can be assumed to account for this discrepancy, for the problem is one involving not an excessive loss but a greater inflow than is in evidence.

It is recognized that the estimate of the surface inflow to Goose Lake may be 100 per cent or more in error, but even if the inflow is twice as great as has been assumed it will not materially affect the result, giving an apparent increment (and evaporation rate) of only 2.15 feet (25.8 inches) a year, for the surface inflow from the tributary streams is so much less than the direct precipitation on the lake surface that doubling the former does not greatly change the amount chargeable to evaporation.

The best explanation left to account for the discrepancy seems to be that the lake has a great constant source of supply beneath its surface. The several hot springs along the eastern side of its valley render it not improbable that other waters rise along the fault zone

that is believed to exist here and supply the needful extra inflow. With an annual increment of 2.15 feet, which assumes twice the inflow from surface streams that was considered in the table on page 39, a supply from subsurface springs of about 144,000 acre-feet annually, or nearly 200 second-feet, is necessary to admit of an evaporation rate of 40 inches.

If the computed inflow from the tributary streams, 1.66 feet, be taken as a basis, and an evaporation rate of 4 feet be assumed (which seems reasonable from the more open nature of the Goose Lake basin as compared with conditions at Keno), the necessary supply becomes nearly twice as great. Even the smaller of these estimates is a larger amount than the discharge of Ana River and may seem a great deal to be supplied by springs beneath the surface of the lake; but the Ana River springs would flow nearly the same if Summer Lake extended northward so as to submerge them, and they probably did flow even stronger than they do now when the lake occupied its entire basin.

Fall River, 70 miles southwest of the lower end of Goose Lake, has its source in springs discharging 1,500 second-feet, or ten times the flow of Ana River.^a

In the above discussion of the water bodies the most interesting thing brought out is this apparent great subsurface supply of Goose Lake. While the reasoning is admittedly based on little concrete data, the weakest point, that of the amount of its surface inflow, is shown to be really a minor factor in the computation, and hence the deductions are considered worthy of presentation.

HYDROLOGY.

GENERAL STATEMENT.

As distinguished from hydrography, which deals with the streams and their flow, the hydrology, or underground waters, of the county will now be discussed.

Waters that exist beneath the surface of the earth may in general be separated into two classes—those that are found in unconsolidated material, relatively near the surface, and those that circulate within consolidated rocks, generally at greater depths. Between the typical examples of each there are many differences, but in less well differentiated cases there may be no good lines of distinction, so that some subsurface waters might well be placed under either head.

^a Hoyt, J. C., and Clapp, W. B., Progress of stream measurements for 1905: Water-Supply Paper No. 177, U. S. Geol. Survey, 1906, p. 133.

SHALLOW WATER.

UNCONSOLIDATED DEPOSITS.

That usually considered as ground water is found at moderate depths below the surface, in the gravels, sands, and silts of stream valleys, the alluvial material at mountain bases, or the accumulated sediments of lake valleys. In many regions, also, the decay of the country rock to a residual soil results in a loose porous layer that catches and holds a part of the rainfall and furnishes a supply of water for shallow wells.

Thickness and processes of formation.—The depth of loose material, either transported or produced in place by disintegration, depends on the climate, the character of the rock, and other factors, as well as on the surface features of the land. In humid climates, where vegetation is rank, rapid decay of the rocks takes place, this decay being aided by the organic acids formed in decomposing vegetal matter, by the abundant water that carries them downward, and by the disintegrating gases, like oxygen, that the water often contains. J. W. Spencer^a states that in the region about Atlanta, Ga., the rocks are "completely rotted" to a depth of 95 feet, while "incipient decay" may reach to 300 feet; and it is estimated that in some parts of Brazil such agencies have caused the decay of granite to a depth of 1,000 feet or more.

In arid regions, where conditions are less favorable to rock decay through the action of chemical agents, rock removal and the resulting accumulation of débris are largely physical processes. Rapid changes of temperature break up the rock masses, because of the unequal expansion of the minerals of which they are composed, while the winds and the occasional torrential rains carry the disintegrated material to the lower areas, where it accumulates as talus, alluvium, loess, or lacustrine deposits. In addition to its function as a transporting agent, wind also acts powerfully in certain localities as an agent of erosion. The strong wind, laden with particles of dust and sand, becomes an effective natural sand blast and wears away exposed rock surfaces with great rapidity, and the fine particles thus removed accumulate as a part of the mass of loose material in the lowlands.

Ground-water level.—Where the soil has accumulated to sufficient thickness as a result of any or all of these processes, direct precipitation and the inflow from streams keep it saturated below a certain level, except in the most arid districts. This ground-water level is not fixed, but varies with the seasons and with the supply. Its surface has a very definite relation to the land surface, which it resembles in a general way, but it does not rise so high in the hills and often does

^a Geol. Survey Georgia, 1893, p. 82.

not sink so deep in the valleys. Where the land surface intersects the surface of the ground water, as in deep valleys or gorges, springs issue, and as the ground-water level varies with the season these springs fluctuate, drying up when the level of their supply falls below the bottom of the valley and increasing their flow when the ground-water level rises. It is upon such water, saturating at least the lower portions of accumulations of loose material, that nearly all shallow wells depend.

In south-central Oregon the processes of soil formation have made but little progress. On the forested mountains the underlying rock is nearly everywhere in evidence, being covered in most places with only a foot or two of soil. All of the plateaus are rocky, with scarcely enough soil covering to give foothold to the scanty growth of sage. In the valleys, however, there is a fairly deep mantle of soil, an accumulation due chiefly to the contributions of small streams and to material brought by the winds from the higher plateaus. In these sands and silts is found all of the ground water that has thus far been developed in Lake County.

In many localities no definite data were to be had from which to estimate the thickness of such accumulations in the several valleys, but it is thought that in Silver Lake and Christmas Lake valleys it may reach a maximum of between 100 and 200 feet, while in some of the other basins it may be two or three times this depth.

ARTESIAN CONDITIONS IN LAKE AND STREAM DEPOSITS.

Water under sufficient pressure to bring it to the surface when properly tapped is sometimes found in old lake valleys. Streams flowing down from the surrounding slopes brought to the ancient lake alluvial material, which was assorted by the action of the lake water, the coarser being deposited first along the borders, while the finer was held longer in suspension. This assorting action of the water, causing deposition first of the sand and gravel along the margin and later of the finer sediments over these, resulted in the formation of wedgelike layers of sand and gravel, thinning out toward the center of the lake and alternating with layers of fine silts. The drying up of such a lake may leave a fertile valley, underlain by interbedded coarse and fine material, the coarser, thicker, looser beds being exposed in places along the edge of the valley, while the finer materials serve to confine percolating water to them. Thus storage reservoirs in lacustrine material are formed that will supply flowing wells sunk in the lower parts of the valley. The north end of the Colorado Desert, in southern California, is such a valley. Flowing water is obtained in it, chiefly from sand and gravel that underlies the surface at a depth of 450 to 1,000 feet.

In southern California many of the streams are dry or nearly so during the greater part of the year, but each storm swells them to torrents that carry down quantities of material from the mountain slopes to the valleys, where it is dropped. A large share of the water also sinks in the lower slopes. This work of intermittent torrential streams has built up at the mouths of the canyons alluvial cones, which farther out in the valleys have merged together. Coarse and fine materials have thus become interbedded, and wedge-shaped masses of gravels extend into the lowlands. These are in some places underlain and overlain by finer, less pervious materials, and their bases extend far enough up the valley sides to give enough pressure to the water to bring it to the surface when wells are bored. It is from such a source that the artesian water of parts of southern California and of San Joaquin Valley is obtained.

DEEPER WATER.

CONDITIONS OF OCCURRENCE.

As distinguished from the water in the looser, unconsolidated material, there is water that circulates in the porous strata of the underlying rock masses. Typically the shallow water is limited downward by the upper surface of the bed rock upon which the sand and gravel in which it circulates are deposited, while the deeper water is to be found in this bed rock. Its occurrence here and the possibilities of its utilization for irrigation or other purposes depend upon several factors, among which the porosity of the rock is one of the most important. Sandstones, on account of their greater porosity, are the rocks in which deep water is most often found, but it may be found in any porous rock if the other requisite conditions are fulfilled.

STRUCTURES.

The structure or attitude of the rocks is also of very great importance, for upon this depend the circulation of the water, the pressure under which it may be stored, and its accessibility beneath any given area.

In regions of impervious beds alternating with porous layers that are suitably exposed, so as to allow the absorption of a part of the rainfall and snowfall, the structures most favorable to the existence of water under pressure are synclines and monoclines—that is, rocks bent into trough-shaped or saucer-shaped folds or given a general dip in one direction.

The syncline is the ideal structure for flowing wells. The water that enters the porous beds exposed along the edges of a given basin percolates downward toward the lowest portion of the basin, and, collecting there under the pressure of the water higher up in the porous strata, rises toward the surface when tapped.

Faults, or fractures of the rocks, are unfavorable to the collection of water, because the fault planes that break the water-bearing beds furnish it an easy means of escape.

Monoclines that are limited by faults—i. e., tilted blocks—are therefore not favorable structures for deep-water storage; but monoclines that are not broken, but pass into horizontal structure, or whose individual beds thin out down the dip, often yield flowing wells.^a

As has been shown under the heading "Geology," Lake County is underlain by igneous rocks, a condition that at first thought seems fatal to the existence of available deep waters, for igneous rocks are usually compact and in irregular masses, allowing little opportunity for the storage of water or for its orderly circulation, so that it may be developed for economic uses. But the most extensive masses of these Lake County rocks are basalts, which spread out in widely extended sheets over the surface, so that their distribution is much like that of stratified rocks. Accompanying the basalt flows were volumes of fragmental volcanic material. This was also distributed as thin sheets or lenticular masses by streams and by deposition in lakes, and now appears as tuff beds associated with the basalts. This material is in many places more porous than a sandstone, and where other requisite conditions exist may serve efficiently as a water-bearing stratum. The vesicular basalt is itself sometimes regarded as being capable of storing water, but its vesicles are only isolated voids in an otherwise compact rock, not connected passages as in a porous material, and hence circulation of water is practically impossible in them.

In the great scarp that forms the eastern face of Steins Mountains, Russell^b estimated that there are from 80 to 100 layers of coarse "sandstone" interbedded with the basalts; and in the many scarps of Lake County there are layers of light-colored porous material between the individual lava flows, although they are less numerous and less extensive than in the beds farther east.

Thus far no deep borings have been made in Lake County to determine whether these porous beds, in which alone rock water in valuable quantities may be expected, exist beneath the surface, and only by such tests can their presence or absence be proved. It is believed, however, that the probabilities are strong enough to justify the drilling of test wells in a few localities.

In other parts of this great lava area, especially in southern Washington, artesian water is obtained from sediments associated with the basalt, and it may also underlie portions of Lake County.

^a For further discussion of artesian basins see Water-Supply Papers No. 54, pp. 101-104; No. 78, pp. 10-14; No. 118, pp. 61-67; and Bull. No. 319.

^b Russell, I. C., Artesian basins in southwestern Idaho and southeastern Oregon: Water-Supply Paper No. 78, U. S. Geol. Survey, 1903, p. 19.

In the Harney Basin, 130 miles east of Silver Lake, are the two following wells, which prove the existence of water under pressure beneath that valley, but for lack of proper care and casing these wells do not flow now. In 1893 a well was sunk to a depth of 848 feet about 6 miles southeast of Burns. Water was struck at 350 feet, which rose to the surface and overflowed, and at 840 feet another water-bearing bed was tapped; but in 1902 attempts to improve this well caused the flow to cease. In 1896 a 507-foot well was drilled near Harney, which at a depth between 200 and 300 feet struck water that rose to the surface, but the well was not cased and soon stopped flowing.^a

In discussing the several valleys of Lake County the structural conditions in each will be considered in some detail and the evidence in regard to the probability of securing flowing artesian water will be given.

TEMPERATURES.

In the study of underground waters the temperature offers interesting and often most suggestive evidence. It has been determined by observations in deep wells and mine shafts throughout the world that below the surface layer, about 50 feet in thickness, which is affected by daily and seasonal changes, the temperature increases at a rate of 1° F. for each 50 or 60 feet in depth. So that when wells or springs yield warm waters and it seems likely that their temperatures are not due to exceptional conditions, like proximity to masses of rock heated by volcanic activity, or to a zone of faulting, an estimate may be made of the depth from which they rise. This can not be safely applied to waters that rise along fault zones, because the enormous friction accompanying the faulting produces high temperatures in the adjacent rocks and abnormally heats waters that rise in their vicinity.

In this respect 70° F. is sometimes taken as the temperature above which natural waters are classed as hot,^b while between this figure and the mean annual temperature of the region they are classed as warm. Those springs whose waters are of about the mean temperature, or in winter below it, are classed as cold. This classification is a convenience only and can not be rigidly applied, because as will be at once realized, the same temperature that is called warm in northern latitudes might be classed as cool in equatorial regions, and, indeed, there are places whose mean temperature is above that of the so-called hot waters.

^a Russell, I. C., Artesian basins in southwestern Idaho and southeastern Oregon: Water-Supply Paper No. 78, U. S. Geol. Survey, 1903, pp. 40-41.

^b Peale, A. C., Natural mineral waters of the United States: Fourteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1894, p. 68.

THE LAKE VALLEYS.

WARNER VALLEY.

Warner Valley is a long, narrow depression that extends from north to south in the eastern part of Lake County, and continues into California as Surprise Valley. Its northern portion is only 6 or 8 miles wide, and is bounded on each side by the steep walls that have been described under the headings of "Topography" and "Structure" (pp. 9, 25.)

In the valley bottom there is a string of partially connected alkaline lakes about which are marsh areas that represent for the most part lands from which the waters of the lakes, which are slowly shrinking, have but recently withdrawn. There is both geologic and historical evidence of this shrinkage of the lakes, which are now but remnants of the water body that covered the floor of the whole valley during Quaternary time. Faint beach lines of this former lake are still to be seen in a few places along the sides of the valley, while the litigation mentioned on page 12 is a result of minor changes in level that have taken place within the last half century.

There are but few settlers in the valley, and the agricultural development is limited to small gardens and alfalfa patches and to the harvesting of wild hay from the marsh land as winter feed for cattle and sheep.

Three streams—Warner, Honey, and Twelvemile creeks—flow into the valley from the west or southwest. From each of these a part of the water is diverted for irrigation, but as the supply is small the area thus watered is inconsiderable. These creeks bring down a certain amount of debris and deposit it at the edge of the valley. Honey Creek especially has thus built up a large alluvial fan where it debouches into the lower lands, but the greater part of this material was probably deposited as a delta in the former lake, and this delta is now being rapidly dissected.

Little or no attempt has been made to develop the shallow ground water for irrigation. Water in apparent abundance is obtained in wells only a few feet in depth, but it is used only for domestic purposes and for stock. It is possible that rather deep wells sunk at the outer edges of the alluvial fans of the streams mentioned above would yield flowing water if properly cased, but this would be only in the lower lands, where water for irrigation is of least value. The widest area of cultivable land is in the northern part of the valley, where there are no perennial streams and the region is dry and covered with sagebrush. As elsewhere in the valley, water exists within this area at shallow depths, but it is somewhat alkaline, and it is improbable that this land could be successfully farmed with such irrigation water as could be developed locally.

The structure of Warner Valley is unfavorable to the existence of water under pressure in the porous beds of the basaltic series underlying the alluvium and lake sediments. The valley owes its origin to faulting, the southern portion being a dropped block faulted on both sides, as shown in the cross section Pl. X, page 66.

The scarp that limits the valley on the west dies out near Plush, so that the northern part of the valley is formed by the lower portion of a tilted block, as shown in the section through Chewaucan Marsh (Pl. X). It has been shown (p. 47) that such faulting is unfavorable to the occurrence of ground water under pressure; hence it is not worth while to undertake deep drilling in the rock underlying this valley in the hope of obtaining flowing water.

GOOSE LAKE VALLEY.

Goose Lake Valley lies in the southern end of Lake County. The lower two-thirds of the lake is in California, but by far the greater portion of the valley is in Oregon, north of the lake. On the east the steep-faced extension of the Warner Mountains borders the valley at only 2 or 3 miles' distance from the lake, but to the north and northwest the surrounding slopes are more gentle and give way to low hills on the southwestern side.

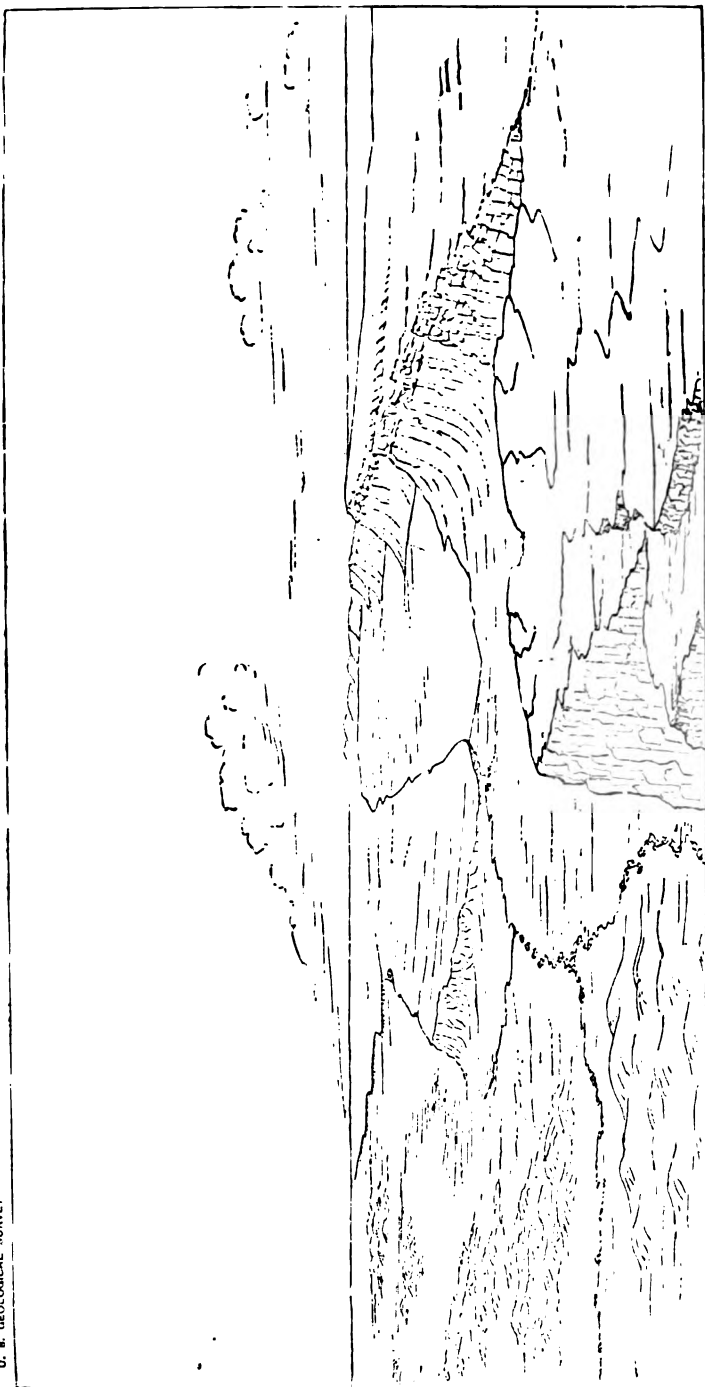
Around the north end of the lake there is marsh hay land, but the upper part of the valley is practically all unreclaimed and is used only for grazing purposes.

Nearly all of the people in this valley live on its eastern side. Lakeview, the county seat, is situated at the edge of the valley a few miles beyond the north end of the lake. Fifteen miles south of it is the town of New Pine Creek, at the Oregon-California line, and between these two towns there are a number of ranches; but on the west and the north sides of the valley there are only a few scattered homes.

Near New Pine Creek a number of orchards and gardens are irrigated by the small streams along the eastern side of the lake, and these, together with shallow wells, supply all of the water at present needed. At Lakeview a good supply of water for the town is obtained from springs in the hills above, and the few private domestic wells reach only to the ground-water level, so at no place in the valley has an attempt been made to get deeper water in the valley sediments.

At the north end of the valley gravel beds have been deposited. These are probably saturated below the ground-water level, and water could be developed by pumps, but the returns to be expected would scarcely warrant this means of irrigation, at least for some years to come.

The filling in of the valley depression by wash from the surrounding slopes, the presence of the lake, much smaller now than in the



SKETCH OF LAKE ABERT, FROM THE SOUTHEAST.

past, and the constant deposition of fine sediments in this lake are genetic conditions favorable to that alternation of coarse and fine deposits essential to artesian flows. It is probable that cased wells of the California type (described on p. 78) and less than 500 feet deep, if sunk in the lowest parts of the valley, west of Lakeview, would yield flowing water; but it is not thought that such water can be developed in the higher, northern part of this valley.

On the eastern edge of the valley, near Lakeview, three hot springs rise, with a temperature of about 173° F. These serve to strengthen the topographic evidence that this, like Warner Valley, has been produced by a faulted block, having the character of the dropped keystone of an anticlinal arch, as shown in the cross section on Pl. X. In such a structural basin, whose origin is almost fatal to the existence of rock water under artesian head, it would be useless to attempt to obtain flowing wells by deep drilling if ever water should be needed for agricultural purposes.

ABERT LAKE BASIN.

In the central part of the county Summer Lake, Chewaucan Marsh, and Abert Lake are in a valley that was once occupied by a single great water body; hence these three now rather distinct basins are topographically one. Structurally, however, they are separate, and therefore they will be separately considered.

Abert Lake lies in the eastern, lowest depression of this valley, in the most typical structural basin formed by a tilted block in this entire region. On its eastern side a cliff rises from the water's edge to a height of more than 2,000 feet, while on the western side the gentle slope of the surface of the tilted block rises to the scarp overlooking Chewaucan Marsh, as is shown in Pl. VIII, reproduced from Russell's article on the region.

As its water level has lowered, the lake has left an extended area of marsh land at its northern end, but little or none along the steeper sides of its basin. This marsh land is controlled by the "X L" ranch, and is used for winter pasture, besides furnishing many tons of wild hay.

A strong spring of good water, 63° F. in temperature, rises at the ranch house and supplies abundant water for stock and for all domestic purposes.

In the northeastern portion of this basin there is some agricultural land where one or two families live, but little attempt has been made to develop water for irrigation. At a number of places along the western shore of the lake there are fresh-water springs of small volume. These are evidently fed by waters that accumulate on the monoclinal slopes between the lake and Chewaucan Marsh, seep down the dip of the basalts, and reach the surface at the lake border.

As there is so little land here possible of reclamation, and hence so little demand for a large water supply, and as, in addition, the geologic structure is so evidently unfavorable, it is scarcely necessary to say that the probability of the occurrence of available rock water under artesian head is very small.

SMALLER VALLEYS.

Near the head of Crooked Creek, about 12 miles south of Lake Abert, in a narrow valley known as Antelope Valley, there are a few settlers. The alluvial soil here seems deep and is capable of growing good crops, but as elsewhere, and under present conditions perhaps most profitably, the land is used mainly as pasture.

Along Coyote and Moss creeks there are also a few settlers, where the streams supply water for small gardens and orchards, and nearly all such small areas have long been occupied by homesteaders.

VALLEY OF CHEWAUCAN MARSH.

The valley occupied in large part by Chewaucan Marsh extends southeastward from where the river of the same name emerges from its canyon to within a short distance of Lake Abert. Its eastern border is the edge of the tilted block that dips under Lake Abert, while the western side is bounded by the steep slopes that separate it from the drainage basin of the river.

Paisley is situated on the banks of the river where it enters the valley. South of Paisley, along the edge of the valley, there are several ranches where grain, alfalfa, and fruits are grown, but north of the town there are no settlements.

The marsh land is under the control of two or three large cattle companies. The river water mostly sinks in this marsh, but by means of drainage canals the land is kept fairly dry, so that great quantities of wild hay are cut from it: Only at The Narrows is there much unproductive alkaline land.

An area of several square miles north of Paisley and the terraces south of the town, against the hills, are covered with gravel brought down by Chewaucan River. A section in this material is exposed at the river bank, just below the Paisley bridge, showing about 4 feet of this gravel overlying 6 or 8 feet of river sands, which in turn overlies finer material, probably lake sediments. A low alluvial divide separates the marsh from Summer Lake Valley, but a well-defined channel still exists in it, through which the two basins were formerly connected.

On the terrace land near Paisley a number of acres of alfalfa are irrigated by ditches that take water from the river a short distance up its canyon. Much land above the level of the present irrigating ditches, at both the northern and the southern ends of the marsh and along the western side of the valley, will be susceptible of cultivation

when water can be supplied to it, but at present it is used only for stock range. The greater diversion of the waters of Chewaucan River for this purpose would no doubt benefit the marsh land also, for much of it is too wet to permit easy harvesting of the wild hay. While it is probable that water for irrigating these higher parts of the valley can best be obtained from storage reservoirs in the upper course of the river, a number of small streams along the western side of the valley could be made to furnish a useful local supply. These streams usually sink in the alluvial fans at the mouths of their gorges, but when traced toward their sources in springs in the mountains above are found to have a considerable flow, which might profitably be piped or flumed to the lands along the edges of the valley.

Like most of the other valleys, that occupied by Chewaucan Marsh has been produced by faulting. The scarp on its eastern side is clear evidence of such movement there, and it is thought that similar deformation has taken place on the western side also, as shown in the cross section, Pl. X, but the evidence on this side of the valley is not so clear.

This structure of course precludes the probability of the existence of available water in the underlying rocks. But in the central part of the basin there is too great an abundance of surface water, the problem at present being rather one of regulation of the supply and of drainage than of the development of additional water; and, as heretofore stated, for irrigating the arid portions of the valley water can probably be best obtained from the river.

SUMMER LAKE VALLEY.

DESCRIPTION.

Summer Lake Valley resembles the basin of Abert Lake in being bounded on one side by a great scarp and on the other by more gentle slopes. On the north rise the slopes of the cross anticline separating it from Christmas Lake Valley, while southward the delta deposits of Chewaucan River divide it from the marsh lands of the river's lower course. The land between the south end of Summer Lake and Paisley is gravelly and is apparently not alkaline. At present it is too arid to be of value for agriculture, but by irrigation it can no doubt be rendered very productive.

STREAMS.

Along its western side, between the rim rock and the lake's edge, numerous streams furnish water for irrigation as well as for domestic purposes, and it is here that most of the ranches of this valley are situated. This is one of the mildest spots in the county, so that nearly all the common vegetables and many varieties of fruit are to be

found in its gardens and orchards; but the tillable land is limited to the narrow strip between the lake and Winter Ridge; hence its area is not great. In the northern part of the valley much of the surface is either arid, sandy, sagebrush land, or a greasewood flat. Near the lake the land is more moist, and here a few settlers have taken up claims, but most of the marsh land is controlled by stockmen.

SPRINGS.

Conditions of occurrence.—The largest and best known springs in this region are those that issue through the sediments near the northwest edge of the valley and give rise to Ana River, which flows southward about 5 miles, to Summer Lake. Near these springs the river channel has cut nearly 40 feet deep into the lake deposits, prohibiting easy utilization of its water, but farther down a small part is diverted for irrigation.

The marshy areas around the northern end of the lake are kept moist by numerous springs, some of which form only small marshy spots, while others give rise to streams, such as Buckhorn and Johnson creeks. The temperature of Buckhorn Creek was not measured, but it is said to be somewhat warmer than that of Ana River (66° F.), while that of the two springs supplying Johnson Creek is 10 degrees cooler, or 56° F.

At the Bonham ranch, on the eastern side of the valley, the temperature of the strongest flowing spring is 66° F., the same as that of the springs that supply Ana River. On this ranch, in what is known as Thousand Spring Valley, a number of acres are irrigated naturally by many small springs. By distributing the water through small ditches Mr. J. H. Bonham has reclaimed much of the greasewood flat on his ranch and has greatly increased the original area of marsh hay land, thus demonstrating what water alone will accomplish on these apparent wastes. The water, constantly rising and evaporating tends to increase the alkalinity of the soil, and is insufficient in quantity to permit drainage and the leaching out of the alkali, so that only the natural grasses and salt bushes grow readily. Of the many kinds of trees tried, only a few cottonwoods along one of the ditches have lived.

The tendency of the alkali to rise with the use of water is also shown on the ranches in the northwestern part of this valley, near Ana River. Cultivation and irrigation from shallow wells tapping only the ground water have in several instances caused the garden areas to become so alkaline as to prevent nearly all of the common vegetables from maturing.

At the north end of the valley, in Juniper Canyon, water rises, apparently from a canyon spring or one where water seeps out of a tufa bed exposed along the canyon side. This has only a small flow, and

it is improbable that any considerable amount could be developed here to irrigate the higher valley sides, but as it is the only spring of this character noted it is thought worthy of mention.

At the southeast end of Summer Lake the Woodward hot spring rises, with a temperature of 123° F. The flow in November, 1906, was about 2 miner's inches. The water is used for irrigating garden vegetables and for bathing purposes. The location of the spring is not far from the steep slopes of this side of the valley, and the occurrence is considered additional evidence of faulting here.

Origin of the Ana River springs.—There are additions to the flow of Ana River, probably by seepage along its banks, below the group of five or more large springs at its source that supply the greater part of its flow. Johnson Creek, east of Ana River, has a flow of perhaps 20 second-feet, and the springs of Thousand Spring Valley yield a large aggregate. All told, it is probable that at least 200 second-feet constant flow rises through the silts and alluvium in this end of Summer Lake Valley.

The question of the source of this water is one that interests all who visit the springs. The region is semiarid, and the drainage area tributary to Summer Lake is limited and clearly inadequate to supply the water yielded by the strong and remarkably uniform flow of the springs. It has been asserted that Silver Lake is the source of supply, but in the years when this lake dried away completely the flow from the springs did not appreciably lessen.

No large streams discharge directly into the Summer Lake basin, but Chewaucan River discharges into the same topographic depression just south of the alluvial divide that separates that basin from Chewaucan Marsh. It has been suggested that water from this stream, which sinks in the sands and gravels, may percolate northward through the porous material that fills the lake basin and, rising beyond the lake, supply the springs in question. But the total mean flow of Chewaucan River during 1906, a year of more than average precipitation, was only 189 second-feet, and the flow during the previous year, of less than average precipitation, was only 93.5 second-feet. The total average discharge of this stream then, is less than the yield of the springs; and much the greater part of this total flows out through Chewaucan Marsh to Lake Abert. The relative elevations of the Ana River springs and the mouth of Chewaucan Canyon are not known. If the springs shall eventually be found higher than the canyon mouth, this fact will at once prove definitely that Chewaucan River water can not be the source from which the springs are supplied. The evidence just given, however, is regarded as practically conclusive, but additional evidence in support of this conclusion is supplied by the temperature of the water of the Ana River springs. This issues at 66° F., which, if the usual increment of 1° above the mean annual temperature for each 50 or 60 feet in depth be accepted, indicates that the

water rises from more than 1,000 feet below the surface. It seems unlikely that the alluvium is this deep near the north rim of the valley, where the springs issue, hence it probably rises from porous beds in the underlying basalt.

The fault that separates Winter Ridge from the valley east of it, since it represents a fracturing of the beds, furnishes a passage upward for any water that may be circulating at depths in porous layers interbedded with the basalts. It is unlikely that this water comes from the eastward, because the known faults in that direction furnish drainage ways through which any confined water can escape, and the intermediate areas are arid.

West and southwest from Summer Lake, however, the topography does not indicate such faulting as is characteristic of the area eastward; it is indicative rather of open folding. Since much of this region is mountainous and timbered and receives a relatively high precipitation, as is indicated by the fact that it is the gathering ground for such large streams as Sprague and Williamson rivers, it seems a competent source of supply even for such large springs as those in question. If the open folding that is indicated exists here, it provides for the exposure of the porous beds in the lavas, so that the water supplied by precipitation may enter them. This folding may also provide sufficient head to force the water eastward up the Winter Ridge monocline into Summer Lake Valley.

Another explanation, which differs slightly from that just given, has been offered. The Summer Lake basin is considered to be a collapsed anticline—a block of the earth's surface that has dropped as a result of the stresses to which the crust has been subjected, and has broken away from the rocks on each side, which are now exposed as the scarps north and west of Summer Lake. It may be that the water of the Ana River springs and the other large springs nearby percolate northward from the region of the upper Chewaucan drainage basin, along the axis of this anticline, and escape to the surface through the faults that mark both the northern edge of the dropped block and the northern edge of Summer Lake Valley.

In both of these explanations the spring waters are regarded as waters that escape from the basalts through the passages that the faults provide. They differ in the assumed source and direction of percolation of these waters. Of the two, that which supposes that they originate in the country west and southwest of Summer Lake is regarded as the more probable.

ARTESIAN POSSIBILITIES.

Shallow water.—The evident saturation of the alluvial and lacustrine deposits over wide areas in the northern end of Summer Lake Valley by water that seeps to the surface or that rises in definite springs suggests the possibility of obtaining flowing water in this

locality by sinking relatively shallow cased wells from 100 to 500 feet in depth. These swampy conditions in areas of marked slope are familiar evidences of the existence of subsurface water under pressure sufficient for the development of flowing wells, and so strong is this evidence in certain parts of this valley that there can be but little doubt that the sinking of cased wells would prove a successful venture.

Whatever the origin of the water in the unconsolidated deposits, it is clearly present in some quantity. As it now rises naturally by seepage over wide areas, it is very harmful to the land, depositing as it evaporates great quantities of alkali, which unfits the soil for agricultural purposes. Wells sunk in the moist land should therefore bring about two beneficial results: First, the present numerous small springs would probably dry up, their yield being concentrated in the relatively few wells, so that it would be much more readily available for irrigation; and secondly, the drying up of these seepages would lessen the present rapid rise of alkali and would thereby render the present alkaline lands valuable. Thus the sinking of shallow artesian wells should accomplish both concentration of the water supply and drainage of the swampy land. Thousand Spring Valley and the basins of Buckhorn and Johnson creeks are favorable localities for experimental wells.

Deep water.—In the paragraphs on structure (p. 26) and on the origin of the Ana River springs (p. 55) it has been explained that Summer Lake Valley is probably due to the collapse of an anticline and the consequent dropping down of a great block of the basalts. The bed rock beneath the valley is therefore faulted, and whatever water may be circulating through it is not confined under pressure, but is permitted to leak out along the fault planes into the overlying alluvium. As already indicated, the water yielded by the great springs of this area probably has this origin. But this leakage is a condition unfavorable to the existence of water under pressure in the basaltic rock underlying the sands, gravels, and silts that make up the surface of the valley. It is not expected, therefore, that deep drilling would develop flowing water in the bed rock beneath the valley.

SILVER LAKE VALLEY.

Northwest of Summer Lake Valley, and separated from it by a divide about 500 feet in height, lies Silver Lake, in the southern end of its basin. The lake itself is bounded on the east and on the west by scarps, but northward the valley opens out into a wide area of marsh, beyond whose borders there is much nearly level sagebrush land, at present dry, but cultivable and valuable if water can be applied. From the gentle slopes to the west and southwest three streams, Silver, Bridge, and Bear creeks, more definitely described on pages 31 and 35, flow into Pauline Marsh and thence into the lake. On the north

and east Conley Hills and their southward extension separate the valley from the larger Christmas Lake Valley. Topographically, however, Silver Lake Valley is really a part of this wider area, being connected with it by a broad, low passage extending eastward to Thorn Lake, into which, at periods of very high water, Silver Lake overflows.

Like other areas of similar character, Pauline Marsh is given over to the growth of native grasses that are cut for hay, while drainage ditches carry off much of the superfluous water southward to the lake. The sagebrush land beyond the limits of the marsh can be made productive by irrigation, but at present it is used mainly as a stock range. Only from Bear Creek is water diverted to any extent for irrigation, and this is used only in the extreme western part of the valley.

On the low slopes of the south side of the valley a few springs have produced green patches of pasture land and furnish watering places for the range animals. The largest of these, Thomson and Murdock springs, 3 miles southeast of Silver Lake, flowed about 9 and 25 miner's inches, respectively, in October, 1906. Their temperature (48°) indicates that they are surface springs, not deep seated, though the water may rise from a porous bed along which it has percolated from the slopes of Hager Mountain.

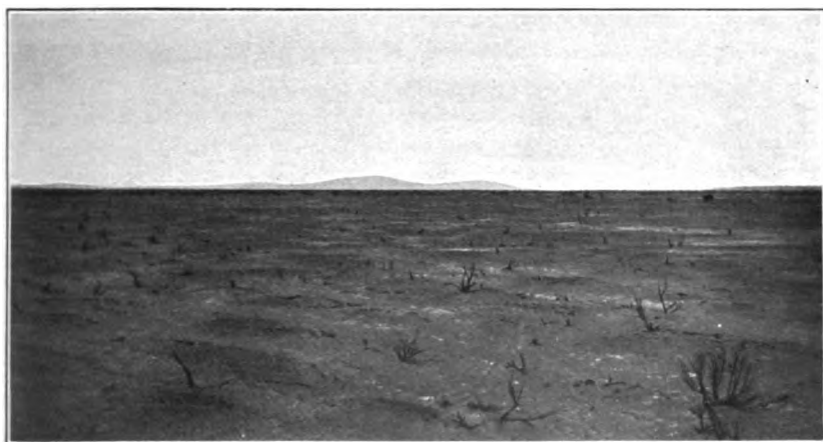
At the town of Silver Lake water is obtained in the 25 or 30 domestic wells in a soft porous material, usually at less than 30 feet below the surface. This seems essentially a subsurface flow, depending for its supply on the run-off from the surrounding slopes, for in winter, when the mountains are snow covered and the ground is frozen, the water level in the wells lowers. The water is of good quality, tests indicating only about 50 parts of alkaline salts in 100,000.

The only attempt to obtain deep water in the area examined has been made at Silver Lake. Mr. F. M. Chrisman, of this place, put down a 6-inch hole on the south edge of the town to a depth of about 250 feet, where the drill became caught and work was suspended. The usual subsurface water was found at a depth of 47 feet, but no other supply was developed, the drill being fast in dry vesicular basalt. A record of the well as kept by Mr. Chrisman shows a depth of 108 feet of clays, sands, and gravels, below which lies a thick tuff bed, probably like that at Fort Rock, underlain by basalt.

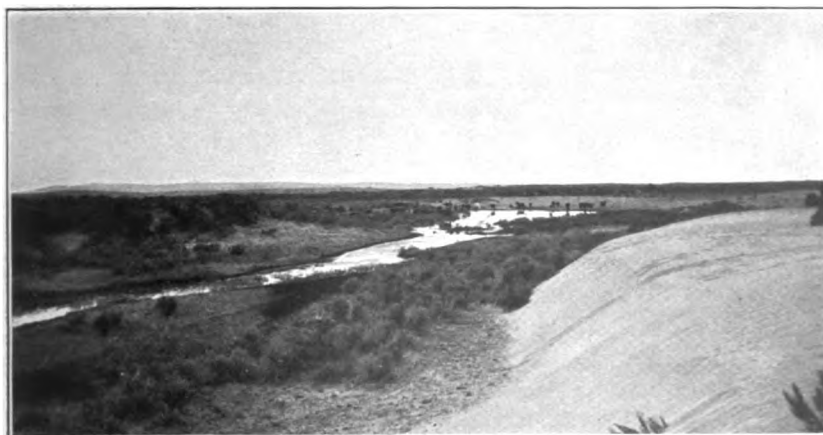
The structure of this basin seems more favorable to the finding of artesian water in the basalts than that of any of the other valleys of Lake County, except perhaps the Christmas Lake desert. On the west and south the slope of the lava beds is toward the valley. To the north also, along the base of Horning Bend, an exposure of tuff indicates that the dip is toward the valley, but on the eastern side this structure is not exhibited. The tuff composing these eastern hills is somewhat folded, but the dips are universally eastward, away from



A. SAGEBRUSH IN CHRISTMAS LAKE VALLEY.



B. AREA IN CHRISTMAS LAKE VALLEY CLEARED BY BURNING.



C. SAND SPRINGS.

Silver Lake Valley. What effect on artesian conditions this structure may have can not be stated definitely, but the Conley Hills and their extension in each direction probably separate it structurally from that of Christmas Lake Valley. Certainly the structural conditions are such as to justify a thorough test by the drilling of a well, 1,000 to 2,000 feet in depth, in the neighborhood of Silver Lake.

Satisfactory evidence of the structural relation of the Conley Hills to the regularly dipping basalts south and west of them, or to the horizontal basalts across the desert on the northeast, was not obtained, but the geologic cross section (Pl. X) is thought to represent the essential features of their relation to the valley on each side at its southern end.

CHRISTMAS LAKE VALLEY.

DESCRIPTION.

The largest valley of the Lake County area, and the one that seems capable of the greatest development, is that of Christmas Lake. Under this name is included all of the country northwest toward Fort Rock, as well as that around Christmas and Fossil lakes. It is an extensive, nearly level plain, 40 or 50 miles long from east to west, but much narrower from north to south. Unlike nearly all of the other valleys, it is not inclosed by steep walls; on all sides the slope to the surrounding basaltic "high desert" areas is gentle. On the west Fort Rock and Table Rock are prominent landmarks from nearly all parts of the valley, as is St. Patrick Mountain on the south, while on the north side of the valley the recent volcanic cones produce a low relief. Within the valley itself two low ridges rise above the sediments—a basaltic tongue extending southward from Bunchgrass Butte, and Sevenmile Ridge, a remnant of tuff like that at Fort Rock, that extends into the valley from its southern border.

Most of the valley floor supports a growth of sage, which in the more sandy areas is tall and dense, as in Pl. IX, A, but over much of the valley is not so thick as to interfere seriously with travel in any direction. In the more alkaline areas the surface tends to bake to a hardpan, over which there is only a scanty growth of grease brush.

Bunch grass and rye grass grow to some extent through nearly all of the valley land, and afford fair range for stock.

SETTLEMENT.

Two years ago there was only one family living in Christmas Lake Valley. In February, 1905, a party of a dozen or more men, neighbors and residents in Willamette Valley, were brought in by a "locator" and took up claims in the region north of Fossil Lake, now

locally known as "Sucker Flat." In the fall of the same year and in the spring of 1906 others came in and settled, chiefly around Christmas and Fossil lakes. Post-offices have been established at

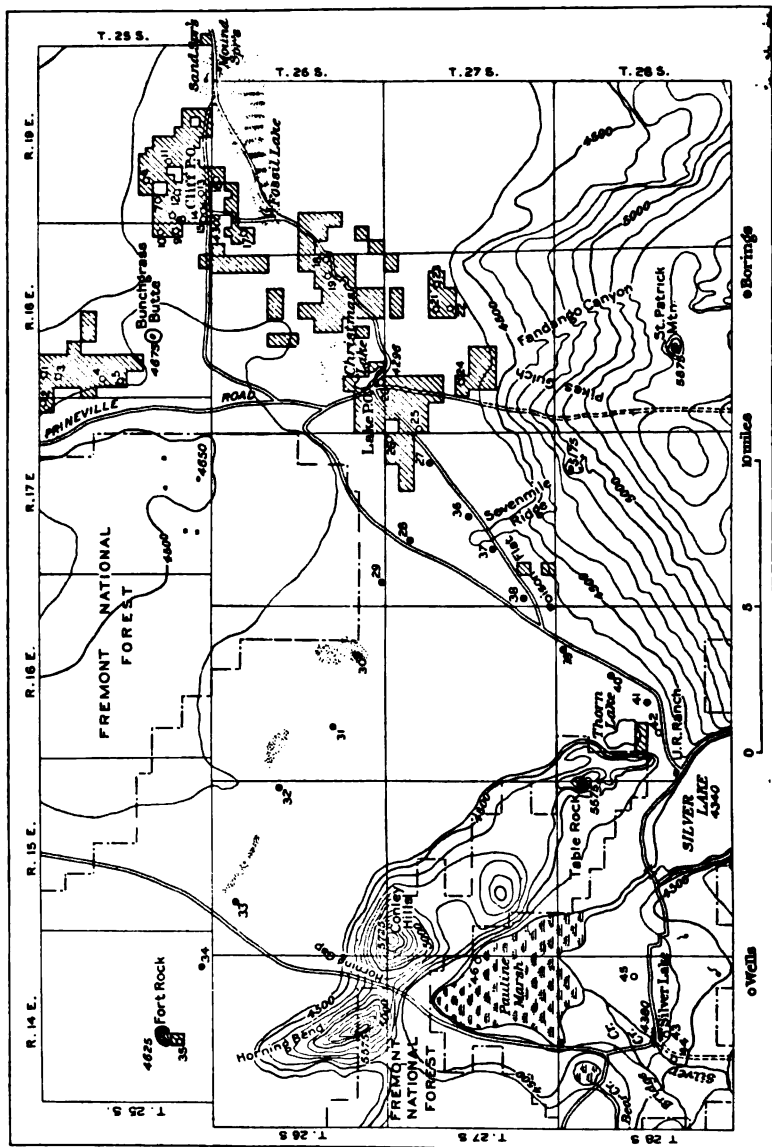


Fig. 1.—Map of Christmas Lake Valley, showing area filed on. Numbers indicate wells and test holes listed in table on p. 64.

Lake and Cliff (named after the locator who brought the settlers in), and a school district has been formed. Nearly all of the claims have been inclosed by substantial barbed-wire fences, the junipers of the

valley sides furnishing good posts for this purpose, and frame buildings have been put up.

About 120 claims had been filed on in the valley up to November 20, 1906. A number took up homesteads; others filed on desert claims. The approximate area filed on is shown in fig. 1.

METHODS OF CLEARING AND FARMING.

As most of the settlers began to clear land too late in the fall of 1905 to permit of burning, nearly all of the area planted the following spring was cleared by grubbing. Owing to the loose nature of the soil this is comparatively easy and gives a field nearly free from brush roots. During the summer of 1906 it was found that on a hot day, with a steady, moderate breeze, the denser patches of sage, once fired, burned completely, the fire often following the roots below the surface. In Pl. IX, *B*, is shown a burned area that was formerly covered with tall brush, like that in Pl. IX, *A*, which shows a view of the tallest, densest sage in the valley, on the sandy land 2 or 3 miles west of Christmas Lake. Dragging with a heavy beam has been tried where the brush is too thin to burn readily, but it is not brittle enough to make this method of clearing successful. Grubbing seems the most practical means on such areas.

Some of the homesteaders have filed on claims, intending to rely on dry farming with constant cultivation, as practiced in Kansas and elsewhere. Most of the grain and vegetables raised during the summer of 1906 (the first season that farming was tried here) matured without irrigation, and showed that the soil is fertile, though as yet rather deficient in humus, or vegetable mold. But 1906 is generally regarded as a favorable year. As indicated by the rainfall records, it was at least as wet as the average, and in drier years such excellent results can not be expected without irrigation.

Records from places of low rainfall show that there are more seasons with less than the average precipitation than there are wet years, for in a wet year there may be twice the average rainfall or more, to balance which would require a year of absolutely no rainfall. As this almost never occurs, a few very wet years serve to keep the average up, hence in arid regions there are more dry years than wet ones.

TENTATIVE IRRIGATION METHODS.

Desert claims.—The desert land acts of 1877 and 1891 provide that a maximum of 320 acres of land may be filed on as a desert claim, but within three years one-eighth of it must be under cultivation, and the whole area under irrigation, except high places evidently not

susceptible of irrigation;^a so that those who have filed on desert claims in this valley realize that they must develop a large supply of water within the next few years.

Pumping.—Pumping has been considered, both by windmills and by distillate engines, from a number of shallow wells, or from large basins scooped out in the soil to ground-water level; for water is found at a shallow depth all through the valley, although not in great abundance nor of good quality. From local observation of the wind during the season of 1906 the writer believes that windmills can not be relied upon to any extent to furnish power, for, as in many other arid sections, during the hot, dry periods there is little or no breeze.

Even if a sufficient flow of ground water can be developed, which from the meager evidence at hand seems doubtful, the present cost of hauling in fuel is not warranted by the returns that may reasonably be expected from the land irrigated. The quality of the sub-surface water should also be taken into account in considering its prospective use for irrigation, for it is all alkaline, at least all of the shallower water, which is all that has so far been developed, and although perhaps its use for the first few years would not be noticeably injurious to crops, its continued use, if not carefully managed, could not fail to be.

Storage reservoirs.—In other parts of the Northwest small storage reservoirs are constructed to conserve the run-off of the stormy season, both for irrigation and to furnish water for stock during the summer. The methods of constructing these reservoirs and the pre-

^aSection 1 of the desert land laws, approved March 3, 1877, provides that any citizen of the United States, or person who has filed his declaration to become such, upon payment of 25 cents an acre may file a declaration that he intends to reclaim a tract of desert land, by conducting water upon it within the period of three years.

Section 2 designates "that all lands exclusive of timber lands and mineral lands which will not, without irrigation, produce some agricultural crop, shall be deemed desert lands."

Section 3 provides that this act shall apply only to California, Oregon, Nevada, Washington, Idaho, Montana, Utah, Wyoming, Arizona, New Mexico, North and South Dakota.

Sections 4, 5, 6, 7, and 8, approved March 3, 1891, further provide as follows: Section 4 provides that at the time of filing his declaration the party shall also file a map showing the mode of contemplated irrigation; section 5, that no land shall be patented under this act until at least \$3 for each acre of the whole tract reclaimed shall have been expended in the necessary irrigation, reclamation, and cultivation. The party must file during each year, with the register, proof that the full sum of \$1 an acre has been thus expended; and "If any party who has made such application shall fail during any year to file the testimony aforesaid, the lands shall revert to the United States, and the twenty-five cents advanced payment shall be forfeited to the United States, and the entry shall be cancelled. Nothing herein contained shall prevent a claimant from making his final entry and receiving his patent at an earlier date than hereinbefore prescribed, provided that he then makes the required proof of reclamation to the aggregate extent of three dollars per acre: *Provided*, That proof be further required of the cultivation of one-eighth of the land."

Section 6 provides that these later sections shall not conflict with any provisions of the act of March 3, 1877.

Section 7 provides that not more than 320 acres may be filed on under this act.

Section 8 states that this act shall apply also to the State of Colorado; and that "no person shall be entitled to make entry of desert land except he be a resident citizen of the State or Territory in which the land sought to be entered is located."

cautions that should be taken to insure their permanence are described in a recent bulletin of the Department of Agriculture.^a

It seems that such reservoirs might prove of value in at least two localities on the edge of Christmas Lake Valley—in the slopes toward the sink of Peter Creek, and south of Christmas Lake, in Fandango Canyon. It is said that at times considerable flood water comes down these slopes, and even during the very general examination of the localities upon which this report is based several favorable reservoir sites were noticed.

In regard to the amount of water that could be thus stored little can be said, for data both as to the extent of the drainage areas and as to the amount of run-off are almost wholly lacking. The latter would no doubt vary between wide limits for different years, and probably a dependable supply could not be counted on to be thus stored for summer use; but this method of conserving water is used successfully elsewhere in the Northwest, and is at least worthy of consideration by settlers in northern Lake County.

In Wyoming and Dakota series of such reservoirs have been constructed in the prairies solely to provide water holes along the trails over which cattle are driven to shipping points. The scarcity of water holes in the high desert area between Christmas and Alkali lake valleys, after the natural sinks have dried up, has been the great drawback to this area as stock range. Low dams built with a comparatively small amount of labor across the lower ends of some of these sinks would greatly increase their storage capacity and the length of time they would serve as water holes, but it is doubtful if such watering places would last all summer. Even the deepest of these sinks were dry in September and October, and evidently had been so for two or three months. It is probable that in this area of indefinite drainage the run-off is so small a percentage of the precipitation, and the tributary drainage areas are so small, that such a means of conserving water for range animals would serve only to lengthen somewhat the high desert range period, but would not extend it throughout the summer. Thus it would be but a temporary expedient.

GROUND-WATER LEVEL.

In order to supplement the data concerning the ground-water level that were obtained from the shallow wells that have been dug, a number of 2-inch auger holes were put down in the unsettled portions of the valley. The locations of these test holes and of the wells examined are shown in fig. 1, and a table of the depths and water levels is given below.

^a Herrman, F. C., Small reservoirs in Wyoming, Montana, and South Dakota: Bull. 179. Office of Experiment Stations, U. S. Dept. Agriculture, 1907. This bulletin may be obtained free of charge by request to Dr. A. C. True, Director, Office of Exp. Stations, U. S. Dept. Agriculture, Washington, D. C.

Wells and test holes in Christmas and Silver Lake valleys.

No. of well. ^a	Owner.	Location.			Depth in feet.	To water in feet.	Material passed through.
		T. S.	R. E.	Sec.			
1	Mr. Beard.....	25	18	6	22	20	Lake silts.
2	(Test well).....	25	17	1	30	(?) 29	Lake silts (water not used).
3	Mr. Gaskell.....	25	18	6	28	25	Lake silts.
4	J. W. Hanley.....	25	18	.....	35	25	Do.
5	Mr. Beard, sr.....	25	18	.....	25	Dry.	0-18, silts; 19-25, rotten basalt.
6	Mr. Whitney.....	25	19	.....	12	11	Lake silts; a little rotten basalt at bottom.
7	Dr. Ewing.....	25	19	.....	10	9	0-6, silts; 6-10, rotten basalt.
8	Dr. Thayer.....	25	19	.....	12½	10	Lake silts.
9	Joe Kasperonez.....	25	18	25	12½	11	Lake silts; a little rotten basalt at bottom.
10	Frank Polte.....	25	18	25	4	Dry.	0-1½, silts; 1½-4, rotten basalt.
11	Mr. Wardall.....	25	19	28	13½	12	Lake silts.
12	James Wilson.....	25	19	29	12	8	Do.
13	{ James McCurdy (3 wells). }	25	19	32	{ 16 14 12	{ 10 10 10	{ 0-4, silts; remaining depth, sand with streaks of clay. Lake silts. Do.
14	John C. Green.....	25	19	31	12	10	Lake silts.
15	W. A. McFargue.....	25	19	31	13	11	Do.
16	Mr. McCurdy.....	26	19	.....	17	15	Do.
17	Mr. Brown.....	26	19	.....	11½	9	Lake silts; a little basalt at bottom.
18	Mr. Lanning.....	26	18	.....	26	24½	Lake silts.
19	M. W. Richmond.....	26	18	.....	31	25	Do.
20	A. W. Long.....	26	18	.....	22	20	Do.
21	.....	27	18	.....	16	13½	Lake silts (?) with basalt fragments.
22	.....	27	18	.....	22	21½	Do.
23	Mr. Lang.....	27	18	.....	23	22	0-16, lake silts (?); 16-23, basalt fragments.
24	J. A. Pond.....	27	18	21	20	20	Alluvium and lake silts.
25	John Ross.....	27	18	7	21	19½	Lake silts.
26	Mr. Anderson.....	27	17	.....	27	20	Do.
27	(Auger hole).....	27	17	.....	20	17	Sandy clay.
28	do.....	27	17	.....	20	.....	Sands and moist clays.
29	do.....	26	17	.....	19½	.....	0-19, sands and moist clay; 19-19½, tuff.
30	do.....	26	16	.....	16	13	Moist clay (at edge of alkaline pool, Pl. III, C).
31	do.....	26	16	.....	3	Dry.	Loose tuffaceous soil (?).
32	do.....	26	15	.....	7½	Dry.	0-4½, silt and sand; 6½-7½, tuff.
33	do.....	26	15	.....	16	12	Silts, sands, and clays; 8-9, moist sand containing fresh-water shells.
34	do.....	25	14	.....	4	Dry.	Loose soil, from decomposed tuff.
35	(Well).....	25	14	.....	26	25	0-25, lake silts; 25-26, tuff.
36	(Auger hole).....	27	17	.....	26	24	Silts, sands, and clays.
37	do.....	27	17	.....	7	Dry.	0-6, silts and sand; 6-7, tuff.
38	do.....	27	17	.....	5	Dry.	0-4, lake silts; 4-5, tuff.
39	do.....	28	16	.....	24	24	0-16, lake silts and clays; 16-24, moist clay.
40	do.....	28	16	.....	5	Dry.	0-4, lake silts; 4-5, tuff.
41	do.....	28	16	.....	4	Dry.	0-3, lake silts; 3-4, tuff.
42	(Well).....	28	16	.....	15	Dry.	Lake silts.
43	F. M. Chrisman.....	28	14	.....	247	49	0-108, lake silts and sands; 108-223, tuff; 223-247, basalt (?).
44	Roy Ward.....	28	14	.....	90	Dry.	Lake silts (?).
45	T. J. La Brie.....	28	14	.....	15	10	Lake silts (near edge of marsh).
46	Hayes Bros.....	27	14	.....	10	5	Do.

^a Locations indicated by corresponding numbers on fig. 1, p. 60.

Throughout the settled area the soil is composed of sands and sediments, which extend to a considerable depth. No coarse gravels are met. The sink of Peter Creek, which at first glance seems to be a separate valley, is really connected with the main valley by a broad drainage channel to the east of Bunchgrass Butte, and the same fine sediments are found in it as in the main part of the valley. In four of the five wells examined in the sink the water level is 20 to 25 feet below the surface, and the water is of good quality, the electrolytic bridge^a indicating an alkaline content of 30 to 40 parts in 100,000. The fifth well is in the southwest end of the so-called sink, near the

^a See footnote on p. 13.

basalt rim. It has been dug 25 feet deep, passing through the usual silts at a depth of about 18 feet, and penetrating the remainder of the distance into decomposed basalt, without finding water.

Several wells along the northern side of "Sucker Flat" have also reached the basalt at depths of 10 or 12 feet. A small amount of water of fair quality has been found at this depth. Well No. 9 also reaches basalt at a depth of 11 feet, but its water is much more alkaline than that of the others. Half a mile north of this well basalt has been found only 2 or 3 feet below the surface, although there is no indication in the character of the brush that the soil here is so shallow. As shown by the wells farther south in the flat, the soil in that part is deeper. Basalt has not been found in them at a maximum depth of 31 feet in well No. 19. The ground-water level varies from about 10 feet below the surface near Cliff post-office to 25 feet near Christmas Lake. The material in which water is found varies in texture from sandy to clayey.

South and west of Christmas Lake the waters are as a rule of better quality than in the area near Fossil Lake. In October, 1906, the water level was about 20 feet below the surface and the mineral content was from 25 to 50 parts in 100,000. In all of the wells it has been noticed that on standing for any length of time the water becomes more strongly alkaline and has an odor as of decaying organic matter. In one well, near No. 15, even though in constant use, the water became so strong as to necessitate the digging of another well.

The wells on the south side of the valley show that the sediments thin out there as on the north. Fragmental volcanic material is met near the bottoms of wells Nos. 21, 22, and 23, which, being from 16 to 23 feet deep, are extended only a foot or so below the water level.

West and northwest of Sevenmile Ridge a number of auger holes were put down, which indicate that the tuff exposed in this ridge, in the hills near Table Rock and in Fort Rock, underlies this part of the valley at shallow depths. Some irregularities in its surface have perhaps formed basins, as at test holes Nos. 33 and 39, where water was found at depths of 12 and 24 feet, respectively; but in others a hard material, probably the tuff, was encountered at 3 to 20 feet below the surface.

A short distance south of Fort Rock a well 25 feet deep has been dug, which passes through 25 feet of the usual light-colored silts into the tuff. The water was 1 foot deep in October, 1906, and although it evidently had been standing a long time, contained only 40 to 50 parts of solids in 100,000.

There were no wells in the southeast arm of the valley and no test holes were sunk in it, but Mr. A. W. Long, of Lake, reports having found water at a depth of 15 feet at one point in this area. Its general character indicates water conditions similar to those near Fossil Lake rather than to those of the western part of the valley.

ANALYSES OF WATERS.

Analyses of three well waters of this valley were made, those of James Wilson (well No. 12), J. C. Green (well No. 14), and John E. (well No. 25). These are given in Table C, on page 72 (samples C and E), and show alkaline contents, respectively, of 36.8, 235, 432.8 parts in 100,000. There is no change in the character of surface to indicate why the water at Mr. Wilson's should be so much purer than that at Mr. Green's, except that the former is nearer edge of the valley. In digging Mr. Ross's well a lump of gypsum (sulphate of lime) a foot long and 6 or 8 inches in diameter was found at a depth of 14 or 15 feet (water being struck at 19½ feet); this may explain the high percentage of sulphate in this water not surprising. The mineral character is distinctly appreciable to the taste.

SPRINGS.

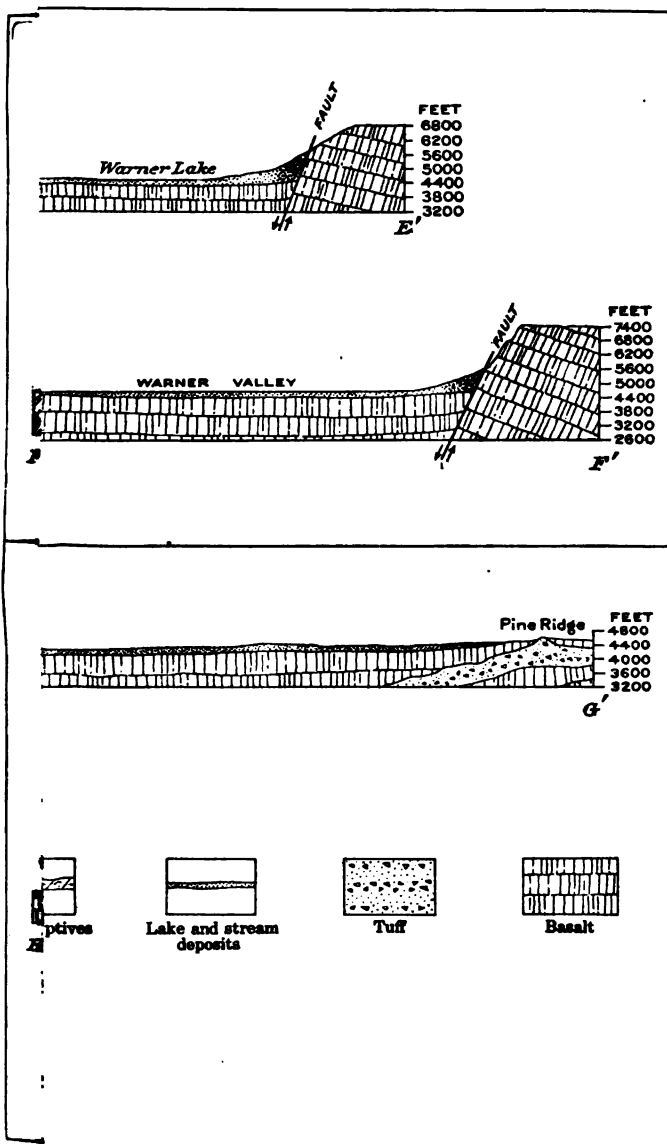
Close to the western shore of Christmas Lake there is a well 9 feet deep, in which the water stands about 5 feet below the surface. Its temperature in October, 1906, was 62° F., both on cold mornings and at midday. Its mineral content is about 40 parts in 100,000. It is said that originally there was a spring here, but that when the willows and nearby sage were cleared off it was soon buried by sand and was reopened only by digging this well.

Christmas Lake is fed by an intermittent spring at its southern end. Fossil Lake is also said to be fed by a spring near its center, from which, it is claimed, range riders have drunk when the lake was dry.

The most interesting springs in the valley are those known as Mound Spring and Sand Springs. These rise in the sands of the area east of Fossil Lake, forming valued watering places for stock. Mound Spring is the larger, having a flow of about 2 miner's inches in October, 1906, which supplied a pond 75 yards across. The water is sulphurous in taste and rises with a temperature of 62° F. Sand Spring, one-third mile northward, are no doubt of the same origin, but the flow is less, being, as nearly as could be measured, about 1½ inches. The nearness of these springs to the sand dunes is shown in Pl. IX, C.

DEEPER ALLUVIAL WATER.

It has been stated in preceding pages that wells along the edges of the valley show that basalt there underlies the sediments at shallow depths. The low dips of the beds in the surrounding basalts, and the basaltic ridge that extends southward from Bunchgrass Butte, indicate that the lake sediments are not very deep at any point in the valley, nor do extensive alluvial slopes exist along its sides. So while a larger supply of better water than that of the present shallow wells may be found deeper below the surface, it does not seem probable that flowing wells can be developed in the lake sediments of this valley.



and Warner Valley. $G-G'$, $H-H'$, Cross sections through

ROCK WATER.

Structural conditions.—The structural conditions affecting the existence of flowing artesian water in the rocks underlying this valley may be stated briefly as follows: All along the valley's southern border the lava sheets dip uniformly toward the valley at low angles; on the eastern side also the slope is gentle toward the valley. The structure to the north is largely obscured by the recent lava flows, but the older beds appear to be nearly horizontal; as exposed where they form the slopes to the sink of Peter Creek, however, they also appear to dip slightly toward the valley. On the west the Conley Hills and the eastward-dipping tuff ridge near Table Rock probably separate Christmas Lake Valley structurally from Silver Lake Valley. Within the valley itself there are at least two irregularities in the shallow basinlike structure. From Bunchgrass Butte a low basalt ridge extends southward toward the projecting scarp on the opposite side of the valley, and in Sevenmile Ridge there is a similar low peninsulalike ridge, but of tuff, pointing toward isolated blocks of the same material on the north side of the valley. In the tentative sections (Pl. X) the structure as interpreted is shown.

From these features it appears that in addition to the general low synclinal structure of the valley as a whole there is also a tendency toward folding along axes trending north and south. If this interpretation is correct the valley is divided into three shallow basins, the eastern basin being that of Fossil Lake, the central that of Christmas Lake, and the third the desert west and northwest of Sevenmile Ridge.

Favorable indications.—These minor secondary folds probably do not affect the likelihood of the existence of artesian water, for they are slight, and tend only to divide the valley, not to prevent the percolation toward it of deep water. The valley as a whole is a structural trough, and therefore the chances of obtaining deep water under pressure seem favorable. The absence of extensive faulting is also a condition which is favorable to the presence of rock water under pressure and which was not found in the southern valleys.

As before stated, the temperature of Mound Spring is 62°, while the mean annual temperature of the valley is about 44°. Assuming the usual increase of temperature with depth as 1° F. for each 50 feet, the water of this spring probably rises from a depth of 900 feet.

The presence of this warm spring, and possibly also the same temperature of the well at Christmas Lake, must be taken as indicating that deep water under pressure does exist under this valley.

In the Connell-Ritzville district, in east-central Washington,^a water is obtained at an average depth of 325 to 400 feet, in decomposed or

^a Calkins, F. C., *Geology and water resources of a portion of east-central Washington: Water-Sup. Paper No. 118*, U. S. Geol. Survey, 1905, pp. 69-75.

fragmental basalt. None of the wells have been cased, but in several artesian pressure causes the water to rise a considerable height above the level at which it is struck, and it probably would rise to the surface if properly tapped. This is in a very gently sloping area, the dip of the beds being hardly appreciable to the eye. It is thought that the water of the district must come from a long distance, from the higher northwestern country, to attain the pressure that it has. Such a condition exists on a larger scale in the northern Mississippi Valley, where the surface exposure of the water-bearing Dakota sandstone is found many miles from the artesian localities.

The Pauline Mountains lie about 30 miles north of Christmas Lake Valley. About the same distance west of Silver Lake Valley is the Walker Range, an eastern spur of the Cascades. Neither of these ranges was visited, but they are thought to consist of the same series of basalts that cover most of Lake County, and it seems not improbable that the rocks dip from them toward Christmas Lake and Silver Lake valleys, and that an underground water supply such as exists in central Washington may reach these valleys from those sources.

On the whole, while the data concerning the underground conditions within these two valleys are meager, the indications in favor of the existence of deep waters are sufficient to warrant the sinking of test wells. This matter has been seriously considered, especially since the settlement of Christmas Lake Valley. During the fall of 1906 it seemed about to assume definite shape, and it is hoped that work on a deep boring will soon be begun.

ALKALI LAKE VALLEY.

One other valley, that of Alkali Lake (Pl. VII, *B*, p. 26), in the northeastern part of the county, was examined in some detail. This valley is about 20 miles long from north to south and about one-fourth as wide, being partially divided into two basins by the spur of hills north of the playa known as Alkali Lake. In each of the basins the surface is nearly level, its chief irregularities being the sand ridges or the hillocks of fine silts previously described. The area around the lake is for the most part a greasewood flat, in which the alkali is very evident; during storms the soil becomes a slippery mud that, on drying, is caked by the soda salts to a hardpan surface. In North Alkali there is some better looking land, but it is rather "spotty," being in some places loose and sandy, with a good growth of sage, and in other places a hard, fine silt with but a scanty covering of greasewood.

On the east the basin is bordered by a scarp which is 1,200 feet in height in its southern portion, but which dies out toward the upper end of the depression. In other directions the basalt slopes rise gently to the higher desert plateau.

Through Venator Canyon on the northeast and a gorge at the northern end gravels have been brought down from the slopes of Little Juniper Mountain, and in the northwestern arm of the valley flood waters have deposited coarse sands and gravels, but elsewhere only fine sands and sediments are to be seen.

The only house in this valley is on the west edge of Alkali Lake. It is a usual stopping place for travelers and range riders, and although permanently occupied by tenants who care for stock on the surrounding range, no attempt has been made at agriculture, for the soil is too alkaline.

In the looser soil at the north end of North Alkali Valley a few acres were cleared by a prospective settler, and grain raised; but attempts to get water failed, several wells reaching basalt at shallow depths, and the claim has been abandoned.

The only spring of importance in this valley is that at the west edge of Alkali Lake, at the only ranch house in the valley, and it has long been known as the only watering place within a radius of 20 miles. It is said that in early days the pool where this spring rises was only 3 or 4 feet in diameter, but of great depth, and that range riders in attempting to sound it let down a weight several hundred feet without reaching bottom. This is the usual legend about desert springs of this character and probably has no foundation in fact. Several years ago a levee was built around the spring to raise its water level and obtain better run-off to the lake, and a pond about 15 yards in diameter was thus formed. In this a weight could be lowered only 15 feet. The temperature of the water in this pond (59°), which is probably less than when it first rises, indicates that it is of deep origin, however; according to previously used assumptions, it comes from a depth of 700 to 800 feet. Small fish live in the pool. In October, 1906, this spring discharged from 2 to 2½ miner's inches, which is its average summer flow, but during the winter its yield is said to be somewhat greater. The water has been reported to contain borax, but although it was not tested for borates, the analysis (sample A, p. 72) shows it to contain only 28 parts of solid matter in 100,000 parts of water, all of which is accounted for in the salts determined.

In North Alkali Valley there is a playa whose surface is about 12 feet below the mean level of the basin. This depression is probably a "blow-out" that has been carved in the lake sediments by wind erosion. Along its northern side, during the spring and early summer, seepage springs furnish water for the range cattle, but they dry up later in the season. Similar springs appear along the northern edge of Alkali Lake after storms and sometimes during periods of cool, cloudy weather. The fluctuation of these springs is of interest in showing the summer lowering of the ground-water level and its

changes due to weather conditions, as well as in indicating a seepage flow southward toward the lake, as would be expected.

Several auger holes that were put down in the valley filling in North Alkali Valley to a depth of 18 or 20 feet show it to be composed of fine silts interbedded with sands, as in Christmas Lake Valley; the water level in November, 1906, was about 15 feet below the surface.

As in the other valleys, water of better quality than that near the surface probably is present near the bottom of the sediments in this basin. But the evidence of extensive faulting along the eastern side of the depression, as at Abert Lake, indicates that deep rock water under artesian head does not underlie this region, and therefore, even if the land were not for the most part too alkaline for agriculture, cheap water for the necessary irrigation would not be available. Hence it seems improbable that more than a few scattered homes can ever be established here.

RECLAMATION PROJECTS.

One-third of the entire area of the United States (exclusive of Alaska and outlying territories) is still vacant public land. But nearly all of this that is susceptible of being tilled lies within the arid regions, or those having an average annual rainfall of less than 20 inches; and there are now in these regions few localities where homes can be easily made, owing to the great cost of developing water. It is for this reason that the Reclamation Service has been established, to aid in settling and rendering productive the great arid tracts, by constructing dams, reservoirs, and canals to supply the needful water for irrigation.^a

Much of the valley land of Lake County was temporarily withdrawn from entry a year or more ago, pending the examination of the Silver Lake, Chewaucan, and Ana River reclamation projects. Part of the

^a The following extracts from the reclamation law, approved June 17, 1902, contain its main terms and provisions:

"SEC. 1. * * * All moneys received from the sale and disposal of public lands in Arizona, California, Colorado, Idaho, Kansas, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oklahoma, Oregon, South Dakota, Utah, Washington, and Wyoming * * * shall be * * * appropriated as a special fund in the Treasury to be known as the 'reclamation fund' to be used in the examination and survey for and the construction and maintenance of irrigation works for the storage, diversion, and development of waters for the reclamation of arid and semiarid lands in the said States and Territories. * * *"

"SEC. 3. That the Secretary of the Interior shall * * * withdraw from public entry the lands required for any irrigation works contemplated under the provisions of this act, and shall restore to public entry any of the lands so withdrawn when, in his judgment, such lands are not required for the purposes of this act; and the Secretary of the Interior is hereby authorized, at or immediately prior to the time of beginning the surveys for any contemplated irrigation works, to withdraw from entry, except under the homestead laws, any public lands believed to be susceptible of irrigation from said works; * * * that public lands which it is proposed to irrigate by means of any contemplated works shall be subject to entry only under the provisions of the homestead laws in tracts of not less than forty nor more than one hundred and sixty acres, and shall be subject to the limitations, charges, terms, and conditions herein provided: *Provided*, That the commutation provisions of the homestead laws shall not apply to entries made under this act.

"SEC. 4. That upon the determination by the Secretary of the Interior that any irrigation project is practicable, he may cause to be let contracts for the construction of the same * * * and * * *

land in Christmas Lake Valley was again restored and opened to entry in September, 1906, but the greater part of the vacant land susceptible of irrigation under these three projects is still withdrawn. These projects are necessarily only tentative, and until several years' measurements of the streams indicate the supply of water that can be depended upon no further action can be taken.

Here, as elsewhere, the Government has taken an important preliminary step toward conserving the water supply by creating the Goose Lake and Fremont forest reserves, for (with the possible exception of Ana River) all the streams are fed from the wooded mountain slopes, where protection and conservation of the scanty supply of moisture is of the utmost importance to any proposed irrigation project.

Under the provisions of the Carey Act^a the construction of a reservoir on the upper Chewaucan River and irrigation of much of the lower land has been considered, but nothing has yet been done.

SOILS.

ANALYSES.

Samples of the soil and water were collected at several places in the county and were analyzed by Mr. W. H. Heileman, engineer of soils at Berkeley, Cal.

The soils were taken from near the surface of the uncultivated lands, which at the time the samples were collected (in October) probably contained their maximum amount of alkaline salts, so they are not fair samples. They were taken thus on the assumption that after the dry summer months the soil near the surface would be the most alkaline and would indicate the extreme conditions to be met. It is to be regretted, however, that samples of the deeper soil were not obtained, in order that the question whether there is a great quantity of salts present and danger of their rising with irrigation and cultivation, might have been answered.

shall give public notice of the lands irrigable under such project, and limit of area per entry, which limit shall represent the acreage which, in the opinion of the Secretary, may be reasonably required for the support of a family upon the lands in question; also of the charges which shall be made per acre upon the said entries, and upon lands in private ownership which may be irrigated by the waters of the said irrigation project, and the number of annual installments, not exceeding ten, in which such charges shall be paid and the time when such payments shall commence. The said charges shall be determined with a view of returning to the reclamation fund the estimated cost of construction of the project, and shall be apportioned equitably. * * *

"Sec. 5. That the entryman upon lands to be irrigated by such works shall, in addition to compliance with the homestead laws, reclaim at least one-half of the total irrigable area of his entry for agricultural purposes, and before receiving patent for the lands covered by his entry, shall pay to the Government the charges apportioned against such tract, as provided in section four." * * *

^a According to the Carey Act of 1894, the United States may grant and patent to any of the arid States or Territories, free of cost, a total area not exceeding 1,000,000 acres which "the State may cause to be irrigated, reclaimed, occupied, and not less than twenty acres of each one hundred and sixty acre tract cultivated by actual settlers, * * * as thoroughly as is required of citizens who may enter under the desert-land law." After filing an approved map of the land and plan of irrigation, the State is authorized to make necessary contracts and induce settlement, but is not authorized to lease the lands or dispose of them in any way except to secure reclamation. A maximum of 160 acres can be held by one person, and the surplus over cost of reclamation, derived from the sale, is to be held as a trust fund to be applied to the reclamation of other lands in the same State.

Following are the results of the soil and water analyses:

TABLE A.—Alkali content of water extract on surface soils of Lake County, Oreg.

[Figured as sodium salts. Amounts are percentages. W. H. Helleman, analyst.]

No.	Locality.	Water-soluble salts in soil.	Sodium chloride.	Sodium bicarbonate.	Sodium sulphate.	Sodium carbonate.
1	Thousand Spring Valley	1.12	0.30	0.22	0.59	0.02
2	3 miles west of Christmas Lake	.19	.02	.07	.11	0
3	One-half mile south of Christmas Lake	2.85	.75	.07	2.03	0
4	Well No. 21	.17	.02	.09	.07	0
5	North end of sink of Peter Creek	.18	.03	.08	.07	0
6	1 mile south of Fossil Lake	2.46	.30	.08	2.08	0
7	One-half mile east of Cliff post-office	.09	.01	.05	0	0
8	Center of North Alkali flat	.08	.02	.03	0	0
9	Western arm of Alkali basin	.06	.02	.04	0	0

TABLE B.—Plant-food analyses of soils represented in Table A.

[Results are in per cent on air-dry soil. Analysis acid extract; Official Association method. W. H. Helleman, analyst.]

No.	Insoluble residue.	Moisture.	Organic and volatile.	Calcium (CaO).	Phosphoric acid (P ₂ O ₅).	Potash (K ₂ O).
1.....	73.45	1.89	6.50	5.65	0.18	1.11
2.....	77.68	2.79	3.23	1.51	.14	.73
3.....	66.62	3.61	5.80	5.17	.19	1.01
4.....	73.22	3.23	4.08	2.51	.05	.51
5.....	78.67	2.30	5.00	1.88	.11	.30
6.....	58.07	4.20	10.96	10.70	.38	.56
7.....	79.14	1.97	3.65	1.41	.13	.54
8.....	79.24	2.56	4.22	3.16	.12	.51
9.....	76.85	2.33	4.59	1.06	.11	.56

TABLE C.—Analyses of waters from southern Oregon.

[W. H. Helleman, analyst.]

	A.	B.	C.	D.	E.	F.
Total solids a.....	28.00	10.00	36.8	235.00	432.80	22.00
Calcium (Ca).....	1.33	1.28	2.24	5.56	8.20	1.18
Magnesium (Mg).....	.82	.51	1.70	4.80	8.20	6.10
Sodium and potassium (Na+K).....	8.24	1.38	8.35	70.00	128.50	5.48
Sulphate (SO ₄).....	2.90	.17	2.51	88.00	204.00	1.24
Carbonate (CO ₃).....	.00	.00	.00	.00	.00	.00
Bicarbonate (HCO ₃).....	16.66	4.40	25.30	78.80	44.10	11.60
Chlorine (Cl).....	3.44	.61	1.97	15.25	57.40	3.94
Nitrate (NO ₃).....	.00	.00	.00	Trace.	Trace.	.00
Total solids by summation.....	33.39	8.35	42.07	262.41	450.40	29.54

a In a letter accompanying the above analyses Mr. Helleman states that "Total solids" means total mineral solids "determined by evaporating a known portion of the clear water to dryness and weighing the residue. In an evaporation there is always a loss of certain acid radicles, principally carbonate and bicarbonate, or at least a change in these two radicles. The effect of this is to make the total solids as directly determined lower in parts than is the summary of the analysis. There is good ground for assuming that the difference between total solids and the summary of the analysis is due to a loss in the bicarbonates in the total solids determination."

A. Spring at Alkali Lake.

B. Stream at A. Eglis's, Wagontire Mountain.

C. Well of J. Wilson, near Fossil Lake.

D. Well of J. C. Green, near Fossil Lake.

E. Well of John Ross, Christmas Lake Valley.

F. Springs of Ana River.

The most noticeable facts shown by these analyses are the absence of carbonates in the waters and in all the soils except that of Thousand Spring Valley, and the high sulphate content, to which salt the bicarbonate and chloride are of secondary importance. The three soils having highest sulphate content (samples 1, 3, and 6) are also the highest in chloride, containing percentages of these white alkalis that are considered to be the limit of tolerance for nearly any crop. For ordinary crops this limit is usually placed at 0.05 to 0.10 per cent for the carbonate of soda and 0.25 to 0.50 per cent for the chloride, while nearly 1 per cent of the sulphate may be endured. So it is seen that, with the exception of sample No. 1 (from J. H. Bonham's ranch, in Thousand Spring Valley), which has been found by trial too alkaline for plant growth, and Nos. 3 and 6, which were taken from evidently alkaline areas, the surface soils do not contain enough of the alkalis to be seriously detrimental.

SOIL CONSTITUENTS.

In Hilgard's recent work on soils the effects of the several valuable constituents of the soil, as well as of the alkalies, are fully treated. From his deductions the following extracts are taken:^a

INSOLUBLE RESIDUE.

About 69 per cent has been found to be the general average of insoluble matter in soils of arid regions throughout the United States. This consists chiefly of free silica (quartz), but the hydrous silicates, forming most of the material known as clays, are also usually included under this head. With this proportion the soils analyzed are seen to agree fairly well.

LIME.

Physically even a small amount of lime carbonate, by its solubility in the carbonated soil water, will act most beneficially in causing the flocculation of clay and in the subsequent conservation of the flocculent or tilth condition by acting as a light cement, holding the soil crumbs together when the capillary water has evaporated, thus favoring the penetration of both water and air and of the roots themselves. * * * Amounts of lime carbonate in excess of 2 per cent do not add to the favorable effects, except as would so much sand.

As to chemical effects, among the most important are—

1. The maintenance of the neutrality of the soil by the neutralization of acids formed by the decay of organic matter or otherwise.
2. The maintenance, in connection with the proper degrees of moisture and warmth, of the conditions of abundant bacterial life, * * * more especially those of nitrification, thus supplying the readily assimilable form of nitrogen; also in favoring the development and activity of the root bacteria of legumes and of the other nitrogen-gathering bacteria, such as *Azotobacter*. * * *
3. The rendering available, directly or indirectly, of relatively small percentages of plant food, notably phosphoric acid and potash. * * *
4. The prompt conversion of vegetable matter into black, neutral humus and (as shown in the case of the soils of the arid region) the concentration of the nitrogen in

^a Hilgard, E. W., Soils, The Macmillan Company, 1906, p. 379 et seq.

the same, while accelerating the oxidation of the carbon and hydrogen, as shown by S. W. Johnson and others.

7. In alkali soils, according to Cameron and May, it counteracts the injurious action of the soluble salts upon the growth of plants, not only in the form of carbonate, but also in those of sulphate and chloride.

An average arid-region soil as given by Mercker, Halle station, Germany,^a contains 1.36 per cent lime, 0.73 per cent potash, and 0.12 per cent phosphoric acid. For a "good" soil he gives the lime (in a sandy soil) at 0.20 to 0.30 per cent; potash, 0.25 to 0.40 per cent; phosphoric acid, 0.15 to 0.25 per cent; from which it is seen that the arid soils are usually low in phosphoric acid but high in lime and potash.

With these results the soil analyses (Table B, p. 72) are seen to compare fairly well, being (with the exception of No. 6) rather low in phosphoric acid but high in lime. Sample No. 6 contains a very high lime content—too high, in fact, as it may cause marliness and render the soil unfavorable to plant growth unless properly handled.

In general, however, the results of these analyses are satisfactory, showing the soils to be not far different from those of other fertile though arid valleys. They are well supplied with lime, potash, and organic matter, but are rather low in phosphoric acid.

SALTS PRESENT.

Around the lake edges and some playas of the higher lands efflorescent saline crusts form. Ten of these were analyzed to determine the proportion of the several salts present, and the results are given in the following table:

Tests on alkali samples (mostly crusts).

[Results show percentage, figured on material analyzed. W. H. Hilleman, analyst.]

No.	Locality.	Sulphates (SO ₄), Qualitative only except No. 7.	Carbon- ates (CO ₂).	Bicar- bonates (HCO ₃).	Chlorine (Cl).	Calculated as sodium salt.		
						Sodium carbonate (Na ₂ CO ₃).	Sodium bicarbon- ate (NaHCO ₃).	Sodium chloride (NaCl).
1	East side Summer Lake.	Heavy.....	14.28	9.93	0.51	25.28	13.50	0.84
2	South end Christmas Lake.	do.....	6.02	4.65	.38	10.65	6.32	.63
3 ^b	West side Alkali Flat.	do.....	6.74	4.06	6.23	11.93	6.34	10.28
4	Edge of pool in Alkali Flat.	do.....	14.64	9.07	15.35	25.90	12.33	25.31
5	Center of Alkali Flat.	do.....	3.74	8.77	.71	6.62	11.92	1.17
6	Eastern pool northwest of Christmas Lake.	Very heavy.	.60	.13	2.25	1.06	.18	3.71
7	Western pool northwest of Christmas Lake.	(c)	.....	.....	.....	.....	.....	.....
8	Efflorescence in "Sucker Flat."	Heavy.....	.19	.30	1.67	.32	.41	2.75
9	Playa in North Alkali.	do.....	8.07	6.43	5.15	14.28	8.74	8.50
10	North end Lake Abert.	do.....	22.40	10.24	1.54	39.65	13.92	2.54

^a Hilgard, Soils, p. 369.

^b An acid extract showed heavy lime-carbonate content.

^c Practically pure sodium sulphate (99+ per cent).

From these analyses it is seen that the sulphate of soda (Glauber's salt) is the most abundant in all these deposits, as it is in the soils themselves.

The crust that forms over the playa of Alkali Lake is occasionally used as stock salt. As before stated, borax claims have been located in this flat, but analysis of the material shows it to consist, as elsewhere, of the sulphate, carbonates, and chloride of soda; there can be but little borax (baborate of soda) in this deposit.

The pools about 10 miles northwest of Christmas Lake, from which samples Nos. 6 and 7 were obtained, are shown in Pl. III, *C* (p. 10). The salt, No. 7, is also used for stock, but sometimes with injurious effects on the animals; nor is this to be wondered at, when analysis shows it to be nearly pure Glauber's salt.

ALKALINE SOILS.

The proper treatment of alkaline soils and the methods of farming in arid regions are treated in several bulletins of the Department of Agriculture,^a but a short discussion of the subject may not be out of place here.

THE ALKALIES AND THEIR EFFECTS.

The three chief salts known as alkali are the chloride, sulphate, and carbonate of soda, called respectively common salt, Glauber's salt, and sal soda. The two former are the white alkalies, while the latter is known as black alkali, since it turns organic matter with which it comes into contact brown or black. Borax also sometimes occurs as an alkali, but it is by no means as common as the others. The nitrate and phosphate of soda and the sulphate of potash also occur in nearly all soils, but as nutritive salts, essential to plant life, not as injurious ones.

Plants vary greatly in the amount of alkali they will endure. Members of the Goosefoot family, which includes the saltbushes and beets, will stand much of all three salts, while the legumes (peas and beans) resent small amounts of either. Common salt and Glauber's salt are by no means as harmful as the black alkali. In general—

* * * when present in soils to the exclusion of other salts, 0.05 per cent of sodium carbonate represents about the upper limit of concentration for common crops. One-half of 1 per cent of sodium chloride is commonly regarded as the endurance limit of crops, and 1 per cent of sodium sulphate. Sodium sulphate, then, is the least injurious and sodium carbonate the most injurious of the salts usually constituting the greater part of alkali under ordinary field conditions, while sodium chloride occupies a middle position.^b

^a The following Farmers' Bulletins treat of subjects of especial interest to those living in the arid regions: No. 52, *The Sugar Beet*, 48 pp.; No. 77, *The Liming of Soils*, 24 pp.; No. 88, *Alkali Lands*, 23 pp.; No. 108, *Saltbushes*, 20 pp.; No. 139, *Emmer: A Grain for the Semiarid Regions*, 16 pp.; No. 215, *Alfalfa Growing*, 40 pp.; No. 266, *Management of Soils to Conserve Moisture*, 30 pp. These may be obtained free on application to the Secretary of Agriculture, Washington, D. C.

^b Dorsey, Clarence W., *Reclamation of alkali soils*: Bull. No. 34, Bureau of Soils, U. S. Dept. Agriculture, 1906, p. 10.

The chloride and sulphate seem to act largely by their presence in excess in the sap, reducing the vitality of the plant. The carbonate, attacking the bark of stalks and roots just beneath the surface, blackens it and makes it spongy, virtually girdling the tree or plant. This salt also has the property of puddling the soil when much moisture is present, and forms a hardpan surface.

The effect on plant life of the bicarbonates, which are also present in considerable amount, is but little understood, but it is not in general considered to be detrimental.

Analyses of soils made by Heileman both before and after prolonged irrigation indicate that by flooding methods of irrigation the bicarbonates are to some extent changed to carbonates, seeming to show that the carbonate salts are at all times unstable.

Hilgard ^a also states that when irrigation ditches in sandy land saturate the soil, thus raising the water table and bringing close to the surface the entire mass of alkali salts and keeping them there for some time, "alkali salts originally 'white' will by chemical change become 'black' by the formation of carbonate of soda from the Glauber's salt, greatly aggravating the injury to vegetation."

TREATMENT OF ALKALINE SOILS.

In regions of slight rainfall it is of particular importance that as much of the moisture as possible be kept in the ground, near the surface, where it can best be taken up by plants. The prevention of evaporation is the chief object in this endeavor, and is partially accomplished by shading the ground, as in the case of alfalfa and similar crops that furnish their own shade, by mulching with straw, or by frequent cultivation to keep the upper few inches of soil in a light, porous condition, so as to prevent further rise of moisture to the surface.

In arid lands brought under irrigation the increased evaporation often greatly accelerates the slower natural action of the ground waters in bringing to the surface and depositing soluble salts on evaporation, and regions formerly not alkaline, as the Yellowstone Valley near Billings, ^b may become so by excessive irrigation.

Leaching down and washing out of the soil by thorough irrigation, where there is good underdrainage, is the best way of getting rid of these salts; but if the drainage is poor, the application of a minimum amount of water and cultivation to prevent its rise and evaporation is practiced to keep the salts down below the plant roots. For shallow-rooted crops, as the cereals, deep plowing, to turn the alkaline surface soil under, is also often of great benefit.

^a Hilgard, E. W., Nature, value, and utilization of alkali lands: Bull. No. 128, College of Agriculture, Univ. California, 1900, p. 6.

^b Whitney, Milton, and Means, Thomas H., The alkali soils of the Yellowstone Valley: Bull. No. 14, Division of Soils, U. S. Dept. Agriculture, 1898.

The chloride and sulphate can not be neutralized, but by the application of gypsum (land plaster) the carbonate may be changed to the comparatively harmless sulphate.

Theoretically the amount of gypsum to be applied should be one-third more in weight than the amount of soda in the land, but owing to impurities in the commercial material about twice the theoretical amount is necessary to neutralize all of the soda. It is not necessary to apply it all at once, but this should be done when rains or irrigation will carry the gypsum down and bring it into contact with the sodium carbonate. The gypsum also changes any borax that may be present to the harmless borate of lime. Two hundred pounds to the acre is an ordinary treatment, the effect being noticeable in two or three days by the disappearance of the discolored spots.

If in any of the valleys of Lake County it should be found desirable to use gypsum on parts of the land, it can probably be best obtained at Lime, on the eastern border of the State, where there is a deposit of good quality, as yet but little exploited.

Almost all of the alkaline salts are contained in the upper 4 or 5 feet of soil, and in level unirrigated lands they are often concentrated in the second or third foot. The amount of alkaline salts in a region is thus limited, and, aside from underdraining, may often be directly removed by collecting the crust by sweeping or with scrapers, and sometimes by planting and harvesting varieties of salt bush. Some of these take up nearly one-fifth of their dry weight of salts (mostly common salt), and hence materially reduce the alkaline content of the land.

CONDITIONS IN LAKE COUNTY.

It has been shown that throughout the valley lands of Lake County the chief alkali is the sulphate. The excess of lime in the soil, as has been stated, will to some extent compensate this, and with proper care in irrigating and plowing, it should not cause serious trouble. Neither are troubles from excessive irrigation and rise of the ground-water level apt to be serious in the valleys of Lake County, because of the fairly low present water level and the improbability of development of water to such an extent that it will be used lavishly. From the beginning, however, rather careful irrigation and cultivation immediately afterwards, is advisable, as the salts are much more easily kept down than gotten rid of when they have collected in serious amount.

The high productiveness of the arid lands when brought under cultivation, and the noxious salts removed or kept down, makes them valuable and well worth reclaiming; hence they are receiving more and more attention as other vacant lands become scarcer.

CROPS ADAPTABLE TO ALKALINE SOILS.

Alfalfa when well started will stand a considerable amount of alkali, but the seed is extremely sensitive to black alkali, and is often killed before germination unless gypsum is used in sowing. Sugar beets are also adaptable to alkaline lands. Glauber's salt little affects their sugar-making quality, and a relatively large amount of common salt is required to render them unfit for this purpose. The cereals wheat, rye, and barley also resist moderate amounts of alkali. Root plants, however, such as potatoes, do not do well as a rule, tending to become watery when grown in alkaline ground.

Of fruits, there are few that will grow on the desert tracts where alkali, drought, and frost must to a greater or less extent be endured; but of those suitable to regions subject to frosts grapes, pears, and apples will stand the greatest amount of alkali. Of other trees, for shade or wood, the conifers (pines, firs, cedars, etc.) are very sensitive to black alkali and will not endure much white alkali, hence they are usually debarred from the lower valleys of arid regions. Cottonwoods will grow where water is near the surface, but they can not withstand drought. Other trees, as the red gum, which will withstand strong alkali, are susceptible to frost. Thus it is that, although pines, junipers, and cottonwoods are found along the margins, they do not grow native in the main parts of such valleys, which are given over to sage and salt bushes.

COST OF DEEP WELLS.

As few deep wells have been sunk in southern Oregon, there is among the settlers no definite idea of what such a well may cost. Figures showing the cost in other localities are therefore here introduced to indicate what may be expected in this matter.

In unconsolidated alluvial materials wells are often bored to depths of 50 feet or more, and up to 3 feet in diameter, with forms of the earth auger or lipped bucket. Such an outfit was used successfully in Christmas Lake Valley in the summer and fall of 1906 to put down several wells. This method, of course, can not be used in compacted or coarse material.

In deeper gravels and sands the California or "stovepipe" method is extensively used. In this method short sections of riveted steel pipe from 8 to 14 inches or more in diameter are sunk by hydraulic jacks, sometimes to a depth of more than 1,000 feet. The material within the casing is removed with a sand bucket or sand pump as the sinking proceeds, and the casing is perforated at water-bearing strata by a heavy cutting knife. This method is much used in southern California and in San Joaquin Valley in central California.

The following tables, taken from Water-Supply Paper No. 137 of the United States Geological Survey, indicate the usual costs of such wells near Santa Ana, Cal.:

Cost, per foot, of drilling wells.

	4-inch.	5-inch.	6-inch.	7-inch.	8-inch.	9½-inch.	10-inch.
First 100 feet.....	\$0.30	\$0.30	\$0.35-.40	\$0.40	\$0.40-.50	\$0.60-.65	\$0.65
Additional for each 50-foot increase....	.25	.25	.20-.30	.20-.35	.20-.35	.20-.35	.35

Following is the general price per foot of riveted steel casing made up into 2-foot joints of the sizes and gages generally used. The price varies, of course, with the steel market.

Cost of well casing.

Diameter in inches	Gage.	Price per foot.	Diameter in inches.	Gage.	Price per foot.
4.....	16	\$0.32	8.....	16	\$0.55
4.....	14	.38	8.....	14	.64
5.....	16	.35	8.....	12	.78
5.....	14	.43	9½.....	16	.65
6.....	16	.42	9½.....	14	.75
6.....	14	.50	9½.....	12	.94
7.....	16	.48	10.....	16	.68
7.....	14	.55	10.....	14	.78

It should be remembered that these prices are for the material near centers of population; in a region like southern Oregon, therefore, the freight would make the cost considerably greater.

The hydraulic method has been successfully used in fine sediments where other methods have failed. A powerful jet of water just below the casing loosens the material and carries it upward out of the hole, so that by adding joints at the top the string of casing is rapidly sunk into the silts. Often a 4-inch well can be sunk to a depth of 400 or 500 feet, cleaned out, and perforated in a couple of days. These wells are usually sunk by contract, cased and ready for use, for about \$1 a foot.

For penetrating rock, however, the oil rig, using a heavy drill bit alternately raised and dropped, is the only practical well-drilling outfit. The following costs of drilling in other localities are given to show what may be expected in Lake County if deep drilling is attempted. In southeastern Washington the following prices rule:^a

The charges for well drilling in the southern part of the wheat lands [of Washington] are as follows: In soil, gravel, etc., above basalt, 50 cents a foot; in rock (which is generally in great part massive basalt, though other varieties after the first basalt is struck are not differentiated), \$2.25 per foot for the first 300 feet, and 50 cents per foot

^a Calkins, F. C., Geology and water resources of a portion of east-central Washington: Water-Supply Paper No. 118, U. S. Geol. Survey, 1906, p. 60.

additional for each 100 feet below that depth. Water for the engine, coal, and board for the outfit are furnished by the owner of the ranch.

In the vicinity of Ritzville [Washington] the terms are slightly higher. For the first 300 feet there the charge is \$2.50, and 50 cents higher for each additional 50 feet. On these terms, however, the driller furnishes coal, the cost of which is estimated at about 25 cents for each foot drilled in basalt. In all cases water is guaranteed, and the risk of losing tools (which generally also necessitates abandoning the hole) is borne by the driller. The average cost of a well at these rates is probably not far from \$800, though it reaches a maximum of over \$2,000.

"Stovepipe" wells can probably be sunk with success in Summer Lake and Goose Lake valleys, and possibly also in those of Silver and Christmas lakes. But in the latter two, if drilling for deep water be attempted, the country rock, basalt, will be met beneath the sediments, and will probably have to be penetrated some distance before rock water, if such occurs, is struck. The idea, to some extent prevalent, that water will be found "if one only goes deep enough" is a fallacy; and if the bottom of the basaltic series should be reached and more siliceous rock encountered, like the rhyolite of Gray Butte or of Horning Bend, work might as well be stopped, for there is little hope of striking water-bearing strata in such rock. It is improbable, however, that such material will be encountered in these valleys at depths to which drilling is apt to be carried.

SUMMARY.

The reclamation of the fertile lands in eastern Oregon will depend on the available supply of water, for, as President Roosevelt said in his first message to Congress in 1901, "In the arid region it is water, not land, which measures production." On this account there will probably always remain some fertile land, as in the southwestern part of the United States, irreclaimable for lack of water. While in some parts of the arid regions dry farming of grain is carried on with more or less success, it is improbable that it can profitably be followed in the valleys that have been under discussion.

The supply of surface (stream) water available for irrigation in Lake County is fairly well known, and should it be developed it will by no means be sufficient to irrigate all of the arable land. The underground supply is as yet unknown, but on the whole, as has been shown, the indications seem favorable to the development of such water in the valleys of Silver, Christmas, and Summer lakes at least.

The reclamation of these valleys will not only increase the agricultural wealth of the State, but its stock-raising interests will also be greatly benefited. In severe winters the supply of wild hay from the marshes is very inadequate, and many head of stock perish every year from hunger and exposure.

Grain, alfalfa, and sugar beets promise to be the chief crops in the valleys, and it seems that for several years to come nearly all produce will find a home market. The rocky high deserts will probably never be fit for other than grazing purposes, but if feed can be raised in the valleys, to carry greater numbers of sheep and cattle through the severe weather, the winter losses will be decreased and many more head of stock can be ranged in the country. The scarcity of water on the high deserts during the summer (when it is sometimes 30 miles between water holes) will remain a drawback to the grazing of cattle and sheep over these areas during this season. In other regions, as in Texas, wells have been sunk at intervals of 8 or 10 miles, and wind-mills and troughs supply this deficiency. But until tests have first been made in the more favorable localities, it can not be said whether it is possible or feasible thus to supply water on the Oregon plateaus.

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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, DIRECTOR

WATER-SUPPLY PAPER 221

GEOLOGY AND WATER RESOURCES
OF THE
GREAT FALLS REGION
MONTANA

BY
CASSIUS A. FISHER



WASHINGTON
GOVERNMENT PRINTING OFFICE
1909

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GEOLOGY AND WATER RESOURCES OF THE GREAT FALLS REGION, MONTANA.

By CASSIUS A. FISHER.

INTRODUCTION.

This report is based on field work done during the season of 1906 in connection with a detailed investigation of the geology and coal resources of the Great Falls coal field. It is designed mainly to furnish information regarding the general geology of the region and the prospects for underground water. A brief description of the different geologic formations is given, with statements concerning their structure, general distribution, and water capacity. The surface waters are also described, including their present and proposed uses for irrigation, water power, etc., and the agricultural interests of different parts of the district are briefly discussed.

The region considered comprises that portion of the Great Plains bordering the Rocky Mountain Front Range, which extends from about longitude 110° W. to about $112^{\circ} 30'$ W., and from about latitude 47° N. to about 48° N. It includes the lowlands lying between the Little Belt and Highwood mountains, and extends to the west and north with increasing width to a point about 10 miles north of Teton River. The area comprises about 3,600 square miles, the location of which is shown in the key map in Pl. I (pocket). It is situated in north-central Montana, mainly in Cascade and Teton counties, but includes portions of Fergus, Chouteau, and Lewis and Clark counties. It is bounded on the south and west by the Little Belt, Big Belt, and Lewis mountain ranges, and on the east and north by the Great Plains and Highwood Mountains.

The topographic map used as a base for the geologic map, and also for the water-resources and other maps presented in the report, was, for the eastern part of the district, taken mainly from detailed reconnaissance surveys of the Great Falls coal field, made from a land-subdivision standpoint by the author and his party. Topographic data for the marginal portions of the east half of the map

were also taken from atlas sheets of the Fort Benton and Great Falls quadrangles surveyed in 1896. The map of the western portion of the field was made in greater part from rapid reconnaissance surveys carried on while the underground-water investigation was being made.

Throughout the work valuable assistance was rendered by W. R. Calvert and D. E. Winchester. These gentlemen mapped portions of the area, collected much of the well and spring data, and made field assays of the water. In the areal geologic mapping assistance was given by H. M. Eakin, who measured numerous sections and collected structural data. Much valuable information was furnished by S. B. Robbins, engineer of the Sun River reclamation project, regarding both underground and surface waters of the Great Falls region, and aid was also given by O. C. Mortson and John French.

LITERATURE.

GENERAL STATEMENTS.

Previous observers have given but little information regarding the underground water resources of the Great Falls region. The surface waters, particularly the Great Falls of Missouri River and the Giant Springs, are phenomena that have attracted widespread attention since the earliest explorers followed up the course of Missouri River to the westward. Captain Lewis, of the Lewis and Clark expedition, who visited this region in 1804, was the first to give an accurate account of the Great Falls and Giant Springs, and doubtless other early explorers had been attracted by them and made brief mention of their occurrence in describing the Northwest Territory. The work of the geologists of the Hayden and transcontinental surveys was confined mainly to the region lying east of Great Falls, and with one or two exceptions did not extend into this district. With the development of water power at the Black Eagle Falls, which took place in 1893, a number of articles appeared in the engineering journals describing the power which could be generated in this vicinity by the development of all the large waterfalls. In the Fort Benton folio, published in 1899, which includes a portion of the Little Belt Mountains, the Highwood Mountains, and adjoining plains, attention is called to the favorable prospects for artesian water in a portion of the quadrangle. Since the Government irrigation project has been undertaken in Sun and Teton River valleys, a number of scientific and popular articles have been published dealing principally with the surface waters of the region. Following is a chronological list of the more important papers published on the surface-water resources of the Great Falls region, one of which sets forth the prospects for artesian water in the eastern part of the district.

BIBLIOGRAPHY OF THE MORE IMPORTANT PAPERS RELATING TO THE WATER RESOURCES OF THE GREAT FALLS REGION, MONTANA.*

LEWIS AND CLARK EXPEDITION, 1804-6. (Coues, 4 vols., 1893.) An account of the journey up the Missouri from St. Louis to the Rocky Mountains, thence to the Pacific coast.

Contains description of the region bordering on the Missouri in the vicinity of Great Falls, Mont. The falls of the Missouri were measured and described.

NEWBERRY, J. S. Surface geology of the country bordering the Northern Pacific Railroad. In *Am. Jour. Sci.*, vol. 30, pp. 337-347. 1885.

Includes a brief description of the surface geology in the vicinity of Great Falls, Mont., with special reference to glacial drift.

NEWELL, F. H. Thirteenth Annual Report U. S. Geological Survey, pt. 3. 1892.

The proposed irrigation system of the Sun River valley and the adjacent region is fully described, pp. 371-386, and the rainfall, topography, and amount of reclaimable land are discussed.

NETTLETON, E. S. Artesian and underflow investigation: Senate Ex. Doc. 41, pt. 2, 52d Cong., 1st sess., pp-78. 1892.

Discusses the surface and underground water of Great Falls district in connection with an explanation of the source of artesian water in eastern South Dakota.

PARKER, M. S. Water power of the falls of the Missouri, Great Falls, Mont.. In *Engineering News*, vol. 32, p. 44. 1894.

The several falls of the Missouri are described, and estimates are made of available power. Reference is made to the Giant Springs.

PARKER, M. S. The Great Falls water power. In *Engineering Record*, vol. 31, No. 16, pp. 274-275. 1895.

Gives brief description of the various falls of the Missouri at Great Falls, Mont., and detailed illustrations of the power plant at Black Eagle Falls.

WEED, W. H. Fort Benton folio, Montana. *Geologic Atlas, U. S.*, folio No. 55, U. S. Geol. Survey. 1890.

Discusses the general geology and mineral resources of the region, also the probability of obtaining artesian water in the area east of Otter Creek.

WILLIS, BAILEY. Stratigraphy and structure, Lewis and Livingstone ranges, Montana. In *Geol. Soc. America*, vol. 13, pp. 305-352. 1902.

Describes the physiography of the Lewis and Livingstone mountain ranges and adjoining plains, also character and structural relations of the Algonkian, Carboniferous, Cretaceous, and Quaternary rocks.

NEWELL, F. H. Second Annual Report of the Reclamation Service. 1904. An abstract of a reconnaissance in Sun River valley, Montana, is included.

NEWELL, F. H. Third Annual Report of the Reclamation Service. 1905.

The proposed irrigation project of the Sun and Teton rivers district is discussed. The water supply of the streams, the storage reservoirs available, and the territory subject to irrigation are described.

UPHAM, WARREN. Outer glacial drift. In *Am. Geologist*, vol. 34, pp. 151-160. 1904.

The glacial drift of the Northwestern States, including Montana, is discussed. Reference is made to its effect upon the drainage of the Missouri River system.

LEIBERG, J. C. Forest conditions in the Little Belt Mountains Forest Reserve, Montana, and the Little Belt Mountains quadrangle. Prof. Paper No. 30, U. S. Geol. Survey. 1904.

* Compiled by W. R. Calvert.

The surface waters of the region and their relation to agricultural, grazing, and forest lands, are included in the discussion.

CALHOUN, F. H. The Montana lobe of the Keewatin ice sheet. Prof. Paper No. 50, U. S. Geol. Survey. 1906.

The glacial history of the Great Falls region is given, with a discussion of the effect of glaciation on the drainage system of the Missouri in that area. Reference is made to artesian conditions near Chouteau.

GEOGRAPHY.

GENERAL FEATURES.

The area treated in this report presents a variety of surface features. It lies in a region which is transitional between plain and mountainous topography and includes portions characteristic of both. Its salient features are broad, gently sloping plateaus bordering the adjacent mountain ranges. These plateaus are traversed by numerous mountain streams, which flow through deep and relatively narrow valleys throughout the eastern portion of the district, but toward the west, where the valleys have been developed in softer rocks, they are usually wide and open. Along the southern margin of the area, from Smith River to the eastern end, the surface of the plains rises gradually by sloping plateaus, culminating in a zone of high, hilly country bordering the Little Belt Mountains, which lie farther to the south. East of Belt Creek and north of the area described the Highwood Mountains rise abruptly above the plains as a cluster of high isolated peaks, reaching an altitude of over 7,000 feet. Between the Highwood and Little Belt mountains is the Otter Creek divide, having at its lowest point an altitude of 4,300 feet. To the east of this divide the country is drained by Arrow Creek and its tributaries and to the west by Belt Creek and its most important branch, Otter Creek, from which the above-described divide derives its name.

PLAINS PROVINCE.

Throughout the region which lies to the west of Missouri River the country presents topographic features characteristic of the Great Plains, of which it forms the western margin. It is a region of long, gently sloping plateaus traversed by streams having relatively wide valleys. On the summit of this table-land at many places remnants of higher plateaus occur in the form of isolated buttes or long irregular ridges, of which Teton Ridge forms a notable example. Westward the surface rises by successive plateaus toward the base of the Lewis Mountains; the surface features become more diversified; and there are a number of high isolated buttes south of Sun River which form some of the most conspicuous topographic features of the region. There is a moderate range of altitude in the district. The highest points examined occur along the base of the Little Belt

Mountains, where the more prominent summits rise to an altitude of over 5,000 feet. The lowest point in the district is along Missouri River below Big Falls, where the altitude is 2,900 feet above sea level. The average altitude of the region is between 3,500 and 4,000 feet. The greatest variation in altitude for any locality is about 1,300 feet in a horizontal distance of $1\frac{1}{2}$ miles. This occurs between Belt Creek and the summit of Belt Butte at the town of Belt. In the Plains province the relative altitudes of the summits of the plateaus bordering the valley bottoms range from 300 to 600 feet.

DRAINAGE.

The Great Falls region is drained by Missouri River, which crosses its central portion flowing in a northeasterly direction. Its flow varies greatly at different seasons of the year. High water occurs in the late spring and early summer months, when the greatest amount of snow is melted in the mountains, and the low-water mark is usually reached in the month of September. The principal tributary of Missouri River from the north is Sun River, which rises in the Lewis Mountains and, flowing eastward, joins the Missouri at Great Falls. From the south the most important tributaries are Smith River and Belt Creek, the former entering the Missouri about 7 miles above Great Falls and the latter 10 miles below, outside of the area to which this report relates. Smith River drains an extensive country lying between Big Belt and Little Belt mountains, and Belt Creek drains the northern slope of the Little Belt Range (Pl. II, 4). Teton River crosses the northern part of the area, flowing in an easterly direction. Its principal tributaries are Deep and Muddy creeks, both of which carry considerable water. Throughout the Plains province many of the smaller streams are intermittent, but those draining the northern slope of the Little Belt Mountains always have more or less water, especially in their upper courses.

DETAILED DESCRIPTIONS OF DISTRICTS.

East of the low divide between the Highwood and Little Belt mountains the country slopes gradually northeastward toward Missouri River. It is traversed by several streams draining the slopes of the adjoining mountains. These streams flow through relatively wide valleys that are bordered by gravel-capped terraces of different elevations. Stanford Buttes, a prominent ridge lying between Running Wolf and Surprise creeks, is flat topped, being a remnant of an ancient terrace. To the north and east of this ridge gravel-capped plateaus of lower levels occupy interstream spaces. Toward the Little Belt Mountains the gravel-capped terraces give way to prominent hog-back ridges formed by the sandstone members of the Ellis and

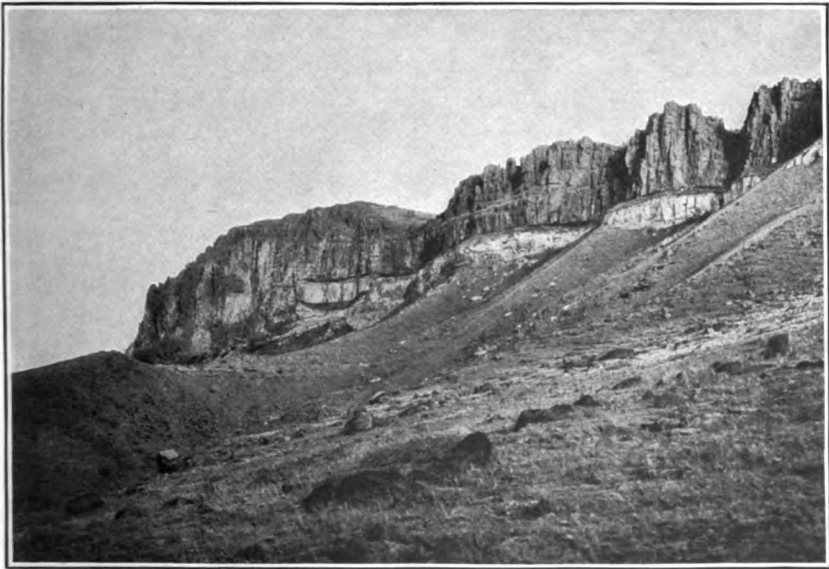
Kootenai formations, which extend in an irregular line of outcrop along the base of the mountains. Skull Butte, a low dome-shaped uplift situated about 6 miles south of Stanford, rises about 200 feet above the surrounding region. South of Skull Butte there are a number of prominent ridges, with long gradual slopes to the north and bold escarpments to the south, which overlook valleys excavated in the soft Quadrant shale. In the southwest corner of T. 16 N. R. 10 E., is located Wolf Butte, a very prominent topographic feature in this part of the area.

Broadly viewed, the district lying between the Otter Creek divide and Missouri River is a high plateau sloping northward and deeply dissected by numerous canyons. Belt and Box Elder creeks, Sand Coulee, and Smith River are the principal streams traversing this region. They all flow through deep, narrow valleys. The altitude of the plateau varies from 3,500 feet along Missouri River to 4,500 feet or more along the southern border of the field. The difference in altitude between valley bottom and plateau summit in the northern part of the area is 300 to 400 feet, but toward the mountains this difference increases to over 600 feet. The streams of this district all flow in a northerly direction, except three of the larger tributaries of Smith River—Boston, Ming, and Goodwin coulees—which flow nearly west. Sand Coulee, which is formed by the confluence of a number of canyon tributaries southeast of Stockett, flows northward for about 10 miles, then turns sharply to the west, and for the remainder of its course meanders through a wide, flat-bottomed valley formed by glacial erosion of Missouri River.

West of the Missouri and south of Sun River the surface rises westward in successive plateaus. The lowest of these plateaus, which lies north of Ulm station and comprises what is locally known as Ulm Bench, has an altitude of about 3,650 feet. West of Ulm Bench is a low saddle separating it from a higher plateau, which in its western extension is surmounted by two isolated buttes forming two of the most conspicuous topographic features of the Plains province. Square Butte, the smaller of the two, is a flat-topped, rectangular-shaped butte, rising abruptly to a height of 500 feet above the surrounding plain (Pl. II, *B*). Fort Shaw Butte, which is in reality a ridge trending northwest, is of equal prominence, but has less precipitous sides. It is less than 1 mile wide, is $2\frac{1}{2}$ miles long, and is located about 2 miles west of Square Butte and almost directly south of Fort Shaw. It has an altitude of about 4,500 feet, rising several hundred feet above the surrounding country. About 3 miles southwest of Shaw Butte is a third, known as Crown Butte, which is also very prominent but somewhat smaller than the two above described. Between Shaw and Crown buttes there is a wide, open valley drained by Little Muddy Creek, a large intermittent stream joining the Mis-



A. DRY BED OF BELT CREEK, NEAR BELT, MONT.



B. NORTHWEST SIDE OF SQUARE BUTTE, SHOWING EAGLE SANDSTONE OVERLAIN BY IGNEOUS ROCK.

souri near Riverdale. South of Little Muddy Creek the surface rises rapidly toward the mountains. Between Sun River and Sims Creek a high gravel-capped plateau of irregular outline occurs, which extends 6 to 7 miles westward. It has an altitude of 3,600 feet and is bordered on the south by the wide, open valleys of Sims Creek and its tributaries. To the west the region consists of prominent ridges and detached buttes, presenting bold escarpments to the north overlooking Sun River valley and long gradual slopes to the south.

Between Sun and Teton River valleys there is a high, gravel-capped, sloping plateau, which continues from the western margin of the district in a more or less modified form to Muddy Creek of Sun River. The southern edge of this plateau is very irregular from the west boundary of the district to a point about 3 miles north of Lowry, but from this point eastward it becomes sharply defined by a line of bluffs about 200 feet high. In its western extension this plateau increases in altitude and culminates in a high crescent-shaped ridge with a bold north-facing escarpment overlooking Deep Creek valley. Eastward the ridge terminates in a number of isolated hills, the larger of which are locally known as Priest Buttes. From Priest Buttes southward to Freezeout Lake the east face of the plateau is deeply serrated by numerous canyons. Bordering this plateau on the east is a belt of level country, imperfectly drained, which is locally known as Freezeout Basin. Near the middle of this basin and at the base of Freezeout Butte is Freezeout Lake, $1\frac{1}{2}$ miles wide and about 3 miles long, which contains water only a small portion of the year. East of Freezeout Basin the surface rises slightly to a level table-land or plateau, which is locally known as the Freezeout Bench. The elevation of this plateau varies from 3,900 to 4,000 feet.

The area between Teton River and its principal tributary from the north, Muddy Creek, is in its central portion a level plateau or bench having an altitude of 3,900 feet. It is locally known as Burton Bench. On the east, where this plateau is crossed by the terminal moraine of the Keewatin ice sheet, its surface is hilly, such as is characteristic of a morainal district, but to the west the surface rises gradually toward the base of the high bluffs occurring on either side of Ralston Gap. West of this prominent line of bluffs the country, which is crossed in its northern part by Muddy Creek, is rolling. North of Muddy Creek there is a low line of bluffs 100 to 200 feet high, the margin of which is included within the area described. Between Teton River and its most important tributary, Deep Creek, is an area containing in its central portion typical badlands topography, with long, irregular ridges culminating in sharp peaks, the most prominent of which are Teton Buttes. On the north

side of this high ridge the surface slopes away to Teton River, while to the south there is a wide, gravel-capped terrace which borders Deep Creek on the north.

GEOLOGY.^a

STRATIGRAPHY.

GENERAL OUTLINE.

The formations occurring at the surface throughout the area to which this report relates consist mainly of sedimentary rocks with igneous intrusions in the form of dikes or laccoliths. The latter occur especially in the regions bordering the adjacent mountain ranges. The strata in general lie nearly horizontal or dip at a relatively small angle to the northeast away from the mountains. They are representative of Carboniferous, Jurassic, Cretaceous, Tertiary, and Quaternary systems. The distribution of these formations, except the Tertiary and certain members of the Quaternary, is shown on the geologic map (Pl. I), and their structural relations, particularly those affecting the occurrence of underground water, are illustrated in the cross sections. The table on pages 15-16 sets forth the order, age, characteristic features, thickness, and water capacity of the formations.

^a A detailed report of the geology of the Great Falls region will appear in Bulletin No. 356 of the Geological Survey.

Geologic formations in the Great Falls region, Montana.

Sys-tem.	Formation.	Character of deposit.	Average thickness.	Water capacity.	Quality of water.	Areal distribution.
Quaternary and Tertiary.	Alluvium.....	Light-colored silt, sand, and clay with local gravel beds.	<i>Feet.</i> 20 to 40	Water bearing.....	Generally good; varies with character of formation from which alluvium is derived.	Occupies valleys throughout the district.
	Lacustrine deposits..	Fine-grained, light-colored silt and clay.	Not determined.	Water bearing.....	Good.....	Occur as a valley filling in all the larger valleys in front of the Terminal moraine.
	Morainal deposits...	Unassorted mixture of sand and gravel in which bowlders of varying size are irregularly scattered, consisting mainly of gneiss, quartzite, granite, and limestone.	Not determined.	Contain some water.....	Variable.....	Occupy the area lying south of Missouli River between Great Falls and Belt Creek; also the area north of that stream across the east side of Fort Benton Bench, along the north side of Teton Ridge, and across the east end of Burton Bench.
	Bench gravels.....	Sand, gravel, sandy clay, and conglomerate.	25 to 40	Generally contain water, although not a large amount; often source of small marginal springs.	Water generally hard, owing to abundance of calcareous cementing material in gravel.	On extensive areas lying east of Otter Creek divide; also highlands between Sun and Teton rivers.
Cretaceous.	Claggett.....	Dull-green and gray sandy shale, clay, and impure sandstone; also massive light-gray and very dark-green, iron-stained conglomeratic sandstone.	670	Probably contains more or less water.	Good.....	On area south of Sun River and west of Crown Butte, also north of Sun River over a part of the district lying west of a line connecting Lowry with Bas Christian's ranch. Areal distribution not shown on map.
	Eagle.....	Massive gray sandstone containing large iron-stained concretions 3 to 10 feet in diameter, which are fossiliferous. Sandstone layers alternating with sandy shale in lower part.	90	Water bearing. Source of springs around Square and Shaw buttes.	Good.....	Exposed underneath the igneous rock capping Square, Shaw, and Crown buttes. Occupies summit of bluffs at Lowry; caps Freezeout and Priest buttes and gives rise to a conspicuous line of bluffs extending northward west of Chouteau past Ralston Gap to the northern margin of the area. Distribution not shown on map.
	Colorado.....	Upper part composed of dark-colored shale with a few thin sandstone layers. Lower part consists of massive gray sandstone, often concretionary, iron-stained, containing thin layers of pebbly conglomerate.	1,800 to 1,800	Shale of upper part of formation generally not water bearing. Basal sandstone members contain large amount of water.	Water from shale highly mineralized. Sandstone contains good water.	Exposed along south side of Highway Mountains from Belt Creek to the east border of the district. Basal sandstones cap the plateau region between Red Buttes and Missouri River. Occupies an extensive area lying between Missouri River and line of bluffs formed by Eagle sandstone above described. Not differentiated from Montana on geologic map.

^a Upper limit of formation not determined.

Geologic formations in the Great Falls region, Montana—Continued.

Systm.	Formation.	Character of deposit.	Average thickness.	Water capacity.	Quality of water.	Areal distribution.
Cretaceous.	Kootenai.....	Massive gray sandstone, red sandy shale and clay with an occasional bed of white limestone. The sandstone predominates throughout the lower portion while red shale, clay, and limestone constitute the upper members. About 60 feet above the base there is a bed of workable coal. Variegated shale and clay containing sandstone layers one above middle of formation, cinnamon brown in color and bone-bearing. Limestone layers sometimes present in lower part.	<i>Fet.</i> 400 to 500	Sandstone members containing large amount of water.	Very good.....	Occupies surface area over a great part of the district lying between Smith River and Belt Creek and is the surface formation of high plateaus south of Otter Creek. East of Otter Creek extends as a narrowing outcrop along northern side of Little Belt Mountains.
	Morrison.....		75 to 120	Sandstone members may contain small amount of water.	Probably would be more or less mineralized.	Outcrops as a narrow band below Kootenai rocks in sides of canyons bordering streams draining northern slope of Little Belt and Big Belt mountains from Smith River to Otter Creek. East of Otter Creek its outcrop zone, which is of varying width, generally occupies the inner face of low hogback ridges of Kootenai rocks bordering the Little Belt Mountains.
Jurassic.	Ellis.....	Dove-colored limestone comprising basal member overlain by reddish-brown, coarse-grained sandstone coarsely conglomeratic at base.	80 to 120	Sandstone member probably contains water.	Water probably hard, for sandstone is bound together by calcareous cement.	Between Smith River and Otter Creek outcrop area limited to canyons traversing the plateau region bordering the Little Belt Mountains.
	Quadrant.....	Sandstone, red and green shale and clay and limestone with an occasional bed of gypsum in lower part.	400 to 500	Contains some water.....	Water generally impure; several sulphur springs issue from this formation.	In the upper part of Belt Creek valley and extending eastward throughout a zone of varying width along the base of the Little Belt Mountains to east end of district.
Carboniferous.	Madison.....	Massive light-gray limestone, white limestone, and more or less argillaceous shale.	100 exposed.	Upper part not water bearing.	.....	In Smith River valley in T. 17 N. R. 3 E., in Sand Coulee and its tributary canyons, in the vicinity of Stockett, and along the northern base of Little Belt Mountains from Belt Creek to east end of district.

CARBONIFEROUS SYSTEM.

MADISON LIMESTONE.

The Madison limestone is very conspicuous, bordering the north side of the Little Belt Mountains, but in the greater part it lies outside of the area here described. The only exposures in the district are found along East Fork of Sand Coulee and its tributaries, where a local doming of the beds exposes about 100 feet of the formation. The distribution of the limestone is shown on the geologic map (Pl. I). Along the flanks of the Little Belt Mountains, outside of the area to which this report relates, the limestone has a thickness of about 1,000 feet, and three members have been recognized by previous workers. The lower member, which is more or less argillaceous, has been called the Paine shale, the more massive limestone of the middle part of the formation the Woodhurst limestone, and the top member the Castle limestone. The Castle limestone forms the "sluiceway canyon," the lower end of which is at Riceville. It is a part of the upper division of Madison limestone, which is exposed at numerous places in the vicinity of Stockett.

That portion of the formation exposed in the area here described consists mainly of limestone, interbedded with calcareous clay. The limestone is usually massive and compact, and is of medium to dark gray color, weathering light. It occurs in beds 10 to 12 feet thick, and is generally relatively pure. At Stockett, 15 feet of oolitic limestone was observed, and at another locality on Ming Coulee, where about 140 feet of the limestone was exposed, the lowest member contains bands of dark-colored chert. Fossils were collected from the limestone at Stockett, also on the head of Ming Coulee, outside the area described.

These fossils have been examined by Dr. G. H. Girty, who regards them as of Mississippian age. In the Little Belt Mountains the Madison limestone is said to carry a typical Mississippian fauna.

The Madison limestone is believed not to be water-bearing, especially that portion which outcrops within this area. Several wells have penetrated the limestone in the vicinity of Stockett and Sand Coulee, and have invariably failed to obtain water.

QUADRANT FORMATION.

The Quadrant formation consists of sandstone, shale, and limestone, with beds of gypsum in the lower part. It lies outside of the area studied except in a few localities, notably on Belt Creek, near Riceville, on Little Otter Creek, $2\frac{1}{2}$ miles above its mouth, along the base of the Little Belt Mountains from Otter Creek to near the southeast corner of the area described, and in the central part of Skull Butte.

In the exposure near Riceville, the basal member of the Quadrant consists of reddish sandy shale with an occasional layer of gypsum. Overlying this member, to which Weed^a has applied the term Kibbey sandstone, the deposits consist largely of shale with interbedded limestone and some sandstone, designated the Otter shale by the same author. The total thickness of the formation as exposed near Riceville is less than 500 feet.

The formation is not important as a water bearer, for throughout the greater part of the district it lies too deep to be reached by ordinary well borings, and as the upper member is shale and limestone and the lower gypsum-bearing soft sandstone, it is highly probable that if water were obtained it would be considerably mineralized. In the vicinity of Wolf Butte a number of sulphur springs issue from the shale members of this formation, and wherever springs are found in it the water contains a large amount of objectionable salts.

JURASSIC SYSTEM.

ELLIS FORMATION.

The Ellis formation is composed of a basal limestone of variable thickness ranging from 20 to 60 feet, above which lies a coarse conglomerate that passes upward into a medium-grained sandstone, light brown in color and more or less thin bedded. The limestone and conglomerate contain Jurassic fossils. Those in the conglomerate are sometimes fragmentary, but more often combined with pebbles of limestone and quartzite several inches in diameter. The component parts of the conglomerate are bound together by a calcareous cement. The total thickness of the formation is about 125 feet, and it rests unconformably upon the Quadrant and Madison formations. Though no practical tests have been made of the water capacity of the formation, it is probable that the sandstone of the upper part would readily absorb water under favorable conditions.

MORRISON FORMATION.

The Morrison formation, which is extensively exposed along the Rocky Mountain Front Range in southern Montana and Wyoming, is also believed to occur along the northern base of the Little Belt Mountains. In previous investigations in this field the Morrison formation has not been recognized, and the beds comprising it have been included in the "Cascade" formation. During the field season of 1906 dinosaur bones, believed by C. H. Gilmore to be of Jurassic age, were found at one horizon in many different localities, and at one exposure,

^a Weed, W. H., *Geologic Atlas U. S.*, folio 55, U. S. Geol. Survey, 1899, p. 2.

about 30 feet below the bone-bearing horizon, a green shale was seen containing a distinctly fresh-water fauna later than the Ellis formation. These sediments, which are here provisionally regarded as constituting the Morrison formation, consist of sandstone and bright-colored sandy shale, with an occasional layer of impure limestone, generally in lenticular form. It lies with apparent conformity on the Ellis, and is overlain conformably by the Kootenai. The thickness varies from 60 to 120 feet, but the exact limits of the formation are often difficult to determine. Fragments of bones have been found at different horizons throughout the overlying Kootenai formation, but thus far none have been discovered in this region sufficiently well preserved for specific determination. It is possible that future investigation may prove that the sediments here tentatively regarded as belonging to the Morrison formation are in reality a basal member of the Kootenai.

The formation is generally exposed in a narrow band on the inner rim of a low ridge formed by the harder overlying rocks of the Kootenai formation. It outcrops all along the base of the Little Belt Mountains from the east end of the district to Smith River. Good exposures occur along the upper courses of Sage, Skull, Running Wolf, Hazlett, Surprise, Geyser, and Otter creeks, and in the bluffs for some distance back from the mountains along Belt Creek, Sand Coulee, Smith River and its principal tributary, Ming Coulee. The following section will show the succession of the beds:

Section of the Morrison formation on the east side of Belt Creek, Montana, in NE. $\frac{1}{4}$ sec. 30, T. 18 N., R. 7 E.

	Feet.
Gray, thin-bedded sandstone.....	17
Pebbly conglomerate occurring in lenses.....	5
Maroon and green shale.....	52
Green shale capped by $1\frac{1}{2}$ feet of gray sandstone.....	5
Calcareous sandstone, weathering light brown.....	5
Green shale.....	20
Massive sandstone, weathering light brown.....	7
Dark-green shale containing thin limestone layers.....	9
Ellis formation.	120

The so-called Morrison formation is believed not to be an important water-bearing formation in this general district. It is composed largely of shale and clay, which are apparently not sufficiently porous to absorb or transmit underground water freely. It is possible, however, that some of its sandy members may contain water; but it is inferred from their lithologic character and the absence of springs throughout their exposed areas that they are not water bearing.

CRETACEOUS SYSTEM.

KOOTENAI FORMATION.

The Kootenai formation includes the upper third of the "Cascade," the Dakota, and the basal red shale included in the Colorado formation as described by W. H. Weed^a in the Fort Benton folio. The name Cascade, as referring to a Cretaceous formation, was first used by that author in his description of the rocks of the Fort Benton quadrangle to apply to a series of beds ranging in thickness from 225 to 500 feet. The lower part of the formation, as originally described, consisted of lavender-tinted sandstone and highly colored shale and clay with massive gray sandstone above containing at its base a workable bed of coal.

During the present investigation, as previously stated, saurian bones, believed by some geologists to be of Jurassic age, were discovered in the lower half of the so-called "Cascade" formation, which indicates that these beds are probably of Morrison age, although vertebrate remains continue to occur to the top of the Kootenai. Between a horizon 45 feet below the coal bed and the top of the "Cascade" formation, as above defined, fossil plants of Kootenai age were collected at four different horizons, which establishes the lower Cretaceous age of this portion of the formation. On the east side of Spanish Coulee, a tributary of Smith River, at a horizon about 150 feet above the "Cascade" formation, in beds the stratigraphic equivalent of which near Belt are regarded provisionally by Weed as of Dakota age, a large collection of Kootenai plants were secured from dark coaly shale associated with red and green shale and clay. Overlying this plant-bearing bed there is about 200 feet of sediment consisting of red shale and sandstone, not differing materially in stratigraphy from beds immediately underlying the plant horizon. For this reason, together with the apparent absence of the Dakota flora in these beds, this member is provisionally regarded as of lower Cretaceous age and included in the Kootenai formation. It is overlain by dark-colored shale and sandstone of the Colorado formation, in the lower part of which were discovered marine saurian remains.

In this report it is not regarded as advisable to employ the name Cascade for the following reasons: The term has not been as extensively used in the literature as the older term Kootenai; its usage would necessitate redefining the term in order to separate its lower member, which is now believed to be Morrison; and the beds immediately overlying the formation can not be differentiated paleontologically from the "Cascade," both being of lower Cretaceous age,

^a Weed, W. H., *Geologic Atlas U. S.*, folio 55, U. S. Geol. Survey, 1899.

rendering it necessary to base the upper limit of the formation in question purely on lithologic grounds.

The Kootenai formation is about 450 feet thick and consists of alternating layers of sandstone and shale with the former predominating, especially in the lower half. The sandstone varies in thickness from 10 to 80 feet and is more or less massive in character. In the upper part shale predominates and is interbedded with thin layers of impure sandstone. At Belt, on the east side of Belt Creek, where a complete section was measured, the basal member of the formation consists of a sandy shale interbedded with sandstone, the latter predominating, and the whole having a thickness of about 60 feet. This member sometimes consists of firm, massive sandstone, with only a small percentage of shale. It is overlain by coal, which here has a thickness of 6 feet, including a few thin partings. Above the coal there is a dark, coaly shale 5 to 6 feet thick, covered by 38 feet of massive light-gray sandstone. This sandstone is followed in ascending order by 138 feet of beds consisting mainly of alternating layers of sandstone, red shale, and clay, with an occasional limestone lens in the lower part. Above this alternating series of sandstone, red shale, and limestone there is about 200 feet of red shale, which constitutes the topmost member of the formation. On the north side of Skull Butte the base of the Kootenai consists of a soft, light-gray, massive sandstone, but in other respects the portion of the formation exposed in this locality agrees closely with the beds exhibited at Belt Butte. A section of the Kootenai on the north side of Skull Butte is given below:

Section of the Kootenai formation on the north side of Skull Butte, Mont.

Reddish sandy shale.	Feet.
Gray thin-bedded sandstone-----	1½
Reddish sandy shale with layers of sandstone in the lower part -----	21
Greenish-gray sandstone, weathering dark, thin-bedded above, clay-ball conglomerate below-----	4
Reddish sandy shale, with layers of sandstone in lower part--	27
Gray cross-bedded sandstone, clay-ball conglomerate in lower part -----	5½
Reddish sandy shale-----	30
Soft, thin-bedded sandstone-----	20
Gray, massive sandstone, clay-ball conglomerate-----	3½
Red sandy shale-----	38
Gray, massive sandstone, clay-ball conglomerate-----	5
Red sandy shale-----	24
Calcareous sandstone, alternating with sandy shale-----	20
Light and dark gray, fine-grained, massive sandstone-----	86
Coal and coaly shale (estimated)-----	6
Soft, massive, gray sandstone-----	62
	353½

Next to the Colorado the Kootenai has the greatest areal distribution of all the formations outcropping within the area. It occupies the surface over a great part of the district lying between Smith River and Belt Creek and is the surface formation of the high plateaus south of Otter Creek. Beyond Otter Creek it is exposed as a band of varying width, which narrows eastward.

The Kootenai is the principal water-bearing formation of the Great Falls region. As above stated, it consists mainly of sandstone and sandy shale. The sandstone is medium to coarse-grained and porous so that it readily absorbs water when the structural conditions are favorable. Along each side of Otter Creek and its tributaries from the south, also in Sand Coulee and its tributaries, the various sandstone members of the Kootenai formation are the source of numerous springs, and in the eastern part of the territory, where this sandstone is overlain by impervious Colorado shale, it contains artesian water.

COLORADO FORMATION.

The Colorado formation is well developed in this general region, being represented by about 1,600 feet of beds. In its type locality in the vicinity of Fort Benton, only a few miles to the north, it is essentially a shale formation, but throughout this region the lower part contains a number of prominent sandstone members. West of Great Falls, where the formation is typically developed, its basal member consists of a soft, massive sandstone somewhat concretionary, which is about 30 feet thick. Above this sandstone there is approximately 35 feet of sediment composed largely of dark-colored shale, with a few sandstone beds. This dark-colored shale is overlain by gray, coarse-grained, massive sandstone, containing concretionary layers and an occasional thin bed of soft, sandy shale, the whole having a thickness of about 80 feet. Above the sandstone for about 300 feet the beds consist mainly of alternating layers of sandstone and shale. These are followed by 700 feet of beds composed largely of uniformly dark-colored shale, which constitutes the uppermost member of the Colorado.

The Colorado formation is exposed throughout a wide area extending along the south side of the Highwood Mountains from Belt Creek southeastward to the east border of the district. Its basal sandstone members occupy the summit of Red Buttes and continue westward as a plateau capping to the Missouri River valley. Smith River and its tributaries cut the basal sandstone of the Colorado, exposing the underlying Kootenai rocks. The Colorado formation occupies the surface of the highland lying between Missouri and Sun rivers, also north and west of these streams to beyond the Teton. Its areal distribution is larger than any other formation within the district.

The shale of the Colorado formation, which constitutes nearly two-thirds of its entire thickness, is not water bearing, but the sandstone comprising its basal portion, which is medium to coarse grained and porous, carries an abundance of water. Throughout Ulm Bench, which is capped by basal Colorado sandstone, a number of wells have been sunk that furnish a large supply of excellent water derived from this formation. It is also the source of well-water supply on the highlands between Smith and Missouri rivers. East of Smith River there are a number of small springs situated along the margin of the detached plateaus which issue from the base of the Colorado sandstone. A typical spring of this character is shown in Pl. V, A.

MONTANA GROUP.

The Montana is extensively developed in the western part of the Great Falls region. It is represented within the area examined by the Eagle and Claggett formations. West of the district fossils were obtained from it which are believed to be of Judith River age. No Pierre shale was recognized in this general vicinity, although the formation is probably represented in the steeply dipping beds that skirt the base of the Lewis Mountains. While no careful examination was made of the Cretaceous formations bordering the base of the Lewis Mountains, it is believed that the various members that constitute the Montana group in the Judith River basin are here represented.

EAGLE SANDSTONE.

The Eagle sandstone consists of massive gray sandstone containing large iron-stained concretions 3 to 10 feet in diameter, which are fossiliferous. Sandstone layers alternate with sandy shale in the lower part. It has a thickness of about 90 feet and is exposed in places underneath the igneous rock capping Square, Fort Shaw, and Crown buttes (see Pl. II, B). It occupies the summits of the bluffs at Lowry where fossils characteristic of the formation were collected. Farther north it caps Freezeout and Priest buttes and gives rise to a conspicuous line of bluffs extending northward west of Chouteau and past Ralston Gap to the northern margin of the district. The distribution of the formation is not shown on the geologic map. The Eagle sandstone is a water-bearing formation, as is shown by the numerous small springs which issue from its base around Fort Shaw and Square buttes.

CLAGGETT FORMATION.

Overlying the Eagle sandstone is the Claggett formation, which consists of dull green and gray sandy shale, clay, and impure sandstone; also massive, light-gray and very dark-green, iron-stained,

conglomeratic sandstone. In the upper part of that portion of the formation exposed in the area examined there is an erosional unconformity, which may be local, exhibiting a marked change in the character of the beds immediately above and below the contact. This apparent unconformity is well exposed on the north face of a high bluff on the south side of Sun River about 7 miles below Augusta, where the following section was taken:

Section of a portion of the Claggett formation on the south side of Sun River, Mont.^a

	Feet.
Sandstone, dark green, conglomeratic, interbedded with sandy, leaf-bearing shale.....	50
Unconformity?	
Sandstone, massive, gray, and sandy shale, fossiliferous throughout.....	125
Sandstone, soft greenish gray.....	95
Shale, sandy and dark green, interbedded with sandstone layers which are concretionary.....	100

The Claggett formation occupies the surface south of Sun River and west of Crown Butte, also north of Sun River throughout a part of the district lying west of a line connecting Lowry with Bas Christian's ranch. The areal distribution of the formation is not shown on the geologic map. The sandstone members of the Claggett formation probably contain more or less water, although as far as could be ascertained no wells have been sunk in them.

QUATERNARY SYSTEM.

TERRACE DEPOSITS.

Throughout a great part of the territory lying east of Otter Creek divide and north of Sun River most of the interstream spaces are capped by bench gravel. This deposit consists of gravel and sand ranging in thickness from 10 to 40 feet and having smooth surfaces sloping gently away from the uplift. The component parts of the gravel, especially in the terraces north of Sun River which have their source to the west in the Lewis Mountains, are mainly sandstone, limestone, and chert, with a small per cent of igneous rock, the whole being sometimes bound together by calcareous cement. In the eastern part of the area the gravel of the terraces is more diversified, containing a larger percentage of igneous rock derived from the Little Belt Mountains to the south.

^a Fossils collected from the locality where the above section was measured are regarded by T. W. Stanton as of the same age as forms collected from the Claggett formation in Judith River basin.

Gravel deposits of four different periods have been recognized. The earlier gravel, which is often cemented into conglomerate, occurs only in limited areas, capping some of the more prominent buttes and ridges, while the later is widely distributed, especially throughout the eastern part of the field. This bench gravel probably ranges in age from Tertiary to later Quaternary age, having been brought down by streams from the Little Belt Mountains and spread by them over the lower plain country as their courses were shifted from time to time. The distribution of the terrace deposits is not shown on the geologic map.

The gravel terraces of the Great Falls district usually contain some water. The amount, however, is not large, and a well sunk in them rarely obtains a sufficient quantity for both stock and domestic purposes of an average-sized ranch. That these gravels contain water, however, is shown by the fact that wherever they occupy extensive areas they are the source of numerous small marginal springs. The water contained in them is derived from rainfall.

GLACIAL DEPOSITS.

Glacial deposits of late Wisconsin age occupy a considerable area throughout the Great Falls region. The terminal moraine of the Keewatin ice sheet enters the district at the east end of Burton Bench, extending south to Teton River, where it turns to the east and follows along the northern side of Teton Ridge to the vicinity of Dutton. From here it extends diagonally southeastward past Benton Lake, across Missouri River to Sand Coulee near Gerber station, where it makes a sharp bend eastward and continues thus past the head of Red Coulee, thence northeastward to Belt Creek, where it passes off the northeast margin of the area. Its location and extent, as worked out by Calhoun,* are shown on the geologic map. The Keewatin ice sheet, extending into the region from the northeast, dammed up Missouri River and its tributaries, forcing the former to abandon its channel in many places, some of which were not reoccupied on the retreat of the ice. The abandoned channel, a portion of which is shown on the accompanying map, extends from the mouth of Sand Coulee, 4 miles south of Great Falls, northeastward in meandering course to the mouth of Belt Creek, where it unites with the present Missouri. In addition to the morainal deposits described above, there was deposited during the occupation of this general region by the ice extensive lake sediments in front of the terminal moraine. Much of this material has been removed by post glacial erosion on the higher lands,

* Calhoun, F. H. H., *Montana lobe of the Keewatin ice sheet*: Prof. Paper U. S. Geol. Survey No. 50, 1906.

but all the larger valleys in front of the moraine are filled with these sediments. Lake deposits of two different periods have been recognized by glaciologists in this region—an earlier and a later deposit. The limits of the earlier lake sediments can be ascertained only by boulders lodged on the summits of the plateaus, while much of the deposits of the more recent lake still remains as a filling in the larger valleys. The distribution of the lake sediments is not shown separately, but is included with the valley wash.

The glacial deposits—especially the more recent lake sediments filling the valleys—are water bearing, and in some places in front of the terminal moraine they are the source of artesian water. The artesian water of Burton Bench is derived from granitic gravels overlain by impervious glacial clays deposited in front of the terminal moraine, and in Box Elder Creek valley is a flowing well, which is believed to have a similar source.

ALLUVIUM.

The alluvial deposits of this general region exhibit the usual diversified character, especially along the larger streams, such as Missouri, Sun, and Teton rivers, the deposits varying in width from one-fourth to 1 mile. The material is composed of fine silt, sand, clay, and gravel, which have been transported by streams in times of high water and deposited at different places along their courses. Along Missouri River from the base of the Big Belt Mountains northeastward to the vicinity of Great Falls the river flows in a meandering course through a wide plateau plain of alluvium, but east of that point it flows through a narrow canyon in which only small detached areas of alluvium are found.

The alluvial deposits generally contain a large amount of water and are the source of well water along nearly all the valleys in this region. The water in this formation is generally relatively pure, although the alluvium of some of the smaller valleys, especially in the Colorado shale areas, contains highly mineralized water.

STRUCTURE.

As the movement of water underground is governed to a certain extent by the structure of the formations, a brief description of the structural relations of the rocks of different parts of the district is here given, attention being called to the manner in which these structures affect the prospects for artesian water. Throughout the Plains portion of the region described the structure is relatively simple and the rocks lie nearly horizontal, dipping with a small angle to the north and east away from the mountains; but in the mountainous portion the structure is more complex.

LITTLE BELT MOUNTAINS.

The general structure of the Little Belt Mountains, which border this area on the south, is that of an anticlinal uplift with sharply dipping sides and a flat summit. In the central portion of the range the stratified rocks lie nearly horizontal, while along the northern flanks of the uplift, as shown on the head of Avoca Creek, the limestone dips at an angle of 15° to 20° toward the lower Plains country. The simple structure of the northern part of the uplift has been considerably modified by the intrusion of igneous rocks in the form of laccoliths, which have caused local doming of the strata in many places. Only one of these laccolithic domes occurs within the area described, but there are others, such as are found east of Kibbey and in the head of Dry Wolf Creek, whose marginal structure extends into this area. In the vicinity of the larger intruded masses of igneous rock the dips are often steep and variable, but in that portion of the mountain front where local intrusions have not disturbed the strata they dip away normally from the uplift at angles of 6° to 12° , lessening gradually toward the lower Plains country, thus producing ideal structural conditions for the occurrence of artesian water on the plains.

HIGHWOOD MOUNTAINS.

The Highwood Mountains, which border on the north the eastern end of the area described, are structurally different from the Little Belt Range. They consist of a group of isolated peaks which have been formed by igneous intrusion in Cretaceous rocks which were horizontally bedded or slightly inclined eastward. Subsequent to this intrusion stream erosion has removed much of the softer rock, leaving the harder rock standing as a cluster of peaks above the surrounding plain.

LEWIS AND BIG BELT RANGES

The Lewis and Big Belt ranges, being more remote from the field investigated, were not examined, but their broader structural features, as worked out by previous investigators, are given below.

The Lewis Mountains, lying to the west of the district and constituting the Rocky Mountain Front Range of northern Montana, have been formed by an overthrust fault of considerable magnitude, extending along the east side of the range, which superimposes Algonkian strata on upper Cretaceous rocks. The extent of the thrust in the vicinity of Chief Mountain, which lies to the north, is said to be 7 miles in a horizontal direction. Under these conditions it is apparent that rocks occupying the surface throughout the adjoining plains on the east will in their westward extension pass under the higher portions of the mountains instead of extending normally up

their flanks, thus producing structural relations not favorable to the occurrence of artesian water in the western part of the Great Falls region. From observations made in the vicinity of Cascade, the northern end of the Big Belt Mountains is formed by extensive masses of igneous rock penetrating upper Cretaceous sediments, which are in some places horizontally bedded and in others sharply folded. It is possible that the overthrust fault which extends along the face of the Lewis Range turns eastward along the northern side of the Big Belt Mountains, but this point was not ascertained in the field.

WATER RESOURCES.

SOURCE.

The source of water supply of the Great Falls region is found mainly in the adjoining mountain ranges. These mountains rise to altitudes of 8,000 to 10,000 feet, where there is a relatively large precipitation and a heavy snowfall. They are covered to a greater or less extent by coniferous forests, and thus serve as natural reservoirs regulating the run-off of the district. The numerous streams traversing the Great Falls region head high in the slopes of the adjoining mountains. Here they gather a large amount of water from melting snow, which is carried out of the mountains into the plains or is absorbed by the upturned edges of the porous rocks over which the streams pass, thus becoming available as artesian water lower down on the plains when the overlying impervious strata are penetrated by well borings. Extensive fires have denuded much of the mountainous land which was formerly densely forested, leaving bare rocks and dead timber and causing the run-off to be more rapid.

SURFACE WATERS.

STREAMS.

MISSOURI RIVER.

The principal stream of the district is Missouri River. It enters the area near Cascade and flows in a northerly direction to the vicinity of Great Falls, where it changes to a more easterly course, continuing thus to the border of the field. That portion of the stream lying above Great Falls flows in a meandering course through a wide valley, but below this point it enters a narrow valley with precipitous bluffs, passing over a number of cataracts collectively known as the Great Falls of the Missouri River (Pl. III, *A* and *B*, and Pl. IV, *A* and *B*). The drainage area of Missouri River at Cascade, Mont., is estimated at 18,295 square miles. Its largest tributaries from the south are Smith River and Belt Creek, and from the west and north Sun and Teton rivers, the latter entering the Missouri in the vicinity of Fort Benton outside of the area to which this report relates.



A. DAM AT BLACK EAGLE FALLS AND THE ANACONDA CONSOLIDATED COPPER AND MINING COMPANY'S SMELTERS, GREAT FALLS, MONT.



B. RAINBOW FALLS OF MISSOURI RIVER, 4 MILES BELOW THE TOWN OF GREAT FALLS, MONT.

There are a number of medium to large size intermittent streams with relatively large drainage areas entering the river from either side. Those from the south are Bird Creek, Castner Coulee, Sand Coulee, Box Elder Creek, and Red Coulee, and from the west Little Muddy Creek. The flow of Missouri River is by no means constant, but varies greatly with the season. According to discharge measurements made at Cascade, Mont., during four consecutive years from 1902 to 1905, inclusive, it had a maximum flow of over 22,000 second-feet and a minimum of about 1,800 second-feet, the mean varying from about 2,000 to 18,000 second-feet. As previously stated, the greatest volume of water is carried by the stream during the months of June and July, and the low-water mark is generally reached in the month of September. The results of observations made on the flow of Missouri River at Cascade are given in the following table:

Estimated rate of discharge of Missouri River at Cascade, Mont., 1902-1905, by months.

[Measurements made by W. W. Schlecht and L. V. Branch.]

Date.	Discharge in second-feet.			Date.	Discharge in second-feet.		
	Maxi-mum.	Mini-mum.	Mean.		Maxi-mum.	Mini-mum.	Mean.
1902.				1904.			
July 17-31	6,900	3,170	4,847	April.....	12,830	5,150	8,409
August.....	2,950	1,810	2,171	May.....	21,710	12,090	14,925
September.....	2,305	1,915	2,067	June.....	20,600	11,350	16,660
October.....	2,950	2,380	2,720	July.....	11,350	3,600	7,436
November.....	4,080	2,550	3,176	August.....	3,480	2,305	2,898
1903.				September.....	2,380	1,915	2,167
April.....	9,300	4,730	6,536	October.....	3,600	2,465	2,979
May.....	12,700	7,700	9,958	November.....	3,600	3,260	3,416
June.....	22,700	12,100	17,958	December.....	4,490	2,740	3,597
July.....	12,700	2,845	7,802	1905.			
August.....	3,420	2,090	2,872	March.....	3,980	3,340	3,721
September.....	2,550	1,970	2,274	April.....	4,320	3,120	3,635
October.....	3,170	2,645	3,066	May.....	4,320	3,450	3,944
November.....	6,300	3,170	4,470	June.....	10,410	4,060	8,081
December.....	9,900	2,740	6,083	July.....	10,070	2,600	4,518
1904.				August.....	2,900	1,800	2,147
January.....			a 6,000	September.....	2,020	1,720	1,929
February.....			a 6,000	October.....	2,600	1,720	2,159
March.....			a 6,000	November 1-27.....	3,980	2,600	3,158

* Estimated.

Discharge measurements of Missouri River at Cascade, Mont., in 1902 and 1906.

[Drainage area, 18,295 square miles.]

Date.	Hydrographer.	Second-feet.
1902.		
July 21.....		5,537
September 9.....		1,891
November 6.....		3,181
1906.		
April 24.....	G. Edson.....	6,190
May 12.....	do.....	7,880
June 8.....	do.....	14,400
June 25.....	Edson and Richards.....	10,400
August 20.....	R. Richards.....	2,300
September 17.....	Grover and Richards.....	2,620
October 31.....	R. Richards.....	8,480

According to measurements of the flow of Missouri River, made by E. T. Nettleton^a in September, 1891, this stream loses 834 second-feet of water between the town of Great Falls and Fort Benton, a distance of about 45 miles. These measurements are supposed to have taken into account the amount added to Missouri River by Belt and Highwood creeks and by Giant Springs. That from the former two is inconsiderable, but the latter adds materially to the total flow.

SUN RIVER.

Sun River, the largest tributary of Missouri River in this district, rises high in the Lewis Mountains. The main stream is formed by the junction of North and South forks of Sun River, which takes place about 3 miles northeast of Augusta in the northwest corner of T. 8 N., R. 5 W. From this point the stream pursues an easterly course through an open valley to Great Falls, where it joins Missouri River. The area drained by Sun River comprises the greater portion of that part of the high eastern slope of the Rocky Mountain Front Range extending from parallel 47° 30' to 48° and a portion of the adjoining Plains province 25 to 30 miles wide extending from the base of the mountains eastward to the vicinity of Great Falls. The high mountainous portion of its drainage area is covered with snow throughout the greater part of the year, while on the adjoining plains more arid conditions prevail. The principal tributary of Sun River from the north is Muddy Creek, which drains the high plateau between Sun and Teton rivers, emptying into the Sun near Vaughn. It is an intermittent stream of minor importance. From the south Sims Creek joins Sun River near the town of Sims, and a few miles farther west Spring and Dry creeks come in from the same side. Sun River has a large flow of water, the maximum being reached during the early summer months when the largest amount of snow is melted on the mountains. By far the greater part of the water of this stream comes from North Fork of Sun River, which is several times larger than South Fork, having its drainage area higher on the slopes of the Lewis Mountains. Discharge measurements of Sun River at the town of Sun River, about 20 miles above its mouth, are given below:

Discharge measurements of Sun River at Sun River, Mont., 1906.

Date.	Hydrographer.	Second-feet.
April 10	Morse and Edson	344
April 15	H. M. Morse	389
May 3	G. Edson	684
May 21	do	1,240
May 22	do	1,160
May 30	do	2,140
June 19	Edson and Richards	1,510
July 16	R. Richards	506
August 17	do	74
October 6	do	204
November 6	Follansbee and Richards	396
November 16	do	b 1,440

^a See Bibliography, p. 9.

^b Ice running; value doubtful.



A. CROOKED FALLS OF MISSOURI RIVER, NEAR GREAT FALLS, MONT.



B. BIG FALLS OF MISSOURI RIVER, 9 MILES NORTHEAST OF GREAT FALLS, MONT.

SMITH RIVER.

Smith River has its source far to the southeast in the vicinity of the Castle Mountains, and flowing northwest drains the highland area between the Big Belt and Little Belt mountains. It enters the area described near the center of the south line of T. 17 N., R. 3 E., and flowing in a northeasterly direction joins Missouri River at a point near Ulm. Within the area described the stream flows in a meandering course through a deep but narrow valley. The gradient of the lower course of the stream is about 7 feet to the mile. The largest tributary of Smith River is Hound Creek, entering from the west, near Orr. It drains the northern end of the Big Belt Mountains, some of its tributaries extending high up the slopes of that range. From the east three intermittent streams enter Smith River—Boston, Ming, and Goodwin coulees. Smith River has a flow of nearly 400 second-feet during the months of May and June, but in the late fall its flow is very much smaller, as is shown by the following discharge measurements:

Discharge measurements of Smith River at Truly, Mont., 1905-6.

Date.	Hydrographer.	Second-feet.
1905.		
March 7.....	Porter and Bird.....	168
May 11.....	Stockman and Porter.....	125
September 1....	A. P. Porter.....	31
1906.		
April 9.....	Morse and Edson.....	423
May 11.....	G. Edson.....	397
July 12.....	R. Richards.....	317
November 28....	do.....	a 79.9

^a Wading section.

TETON RIVER.

The northern portion of the area treated in this report is drained by Teton River. This stream has its source on the eastern slope of the Lewis Mountains, but it does not extend far back into the uplift. After leaving the mountains it pursues a southeasterly course to the vicinity of Chouteau, where it makes a pronounced bend and flows northeastward past Collins and joins Missouri River in the vicinity of Fort Benton. Its largest affluents are Muddy and Deep creeks, the former entering from the northwest below Collins, and the latter from the south near Chouteau. These streams both rise in the foothills of the mountains and have a continuous flow throughout the year. The flow of Teton River is not large, especially in the vicinity of Chouteau, but near the mountains the amount is greater. At a point about 7 miles above Chouteau the stream bed is often dry throughout the late summer months, but, while the surface flow of this portion

of the stream is small, there is apparently a very strong underflow. Spring Creek, a tributary of this stream, is formed by a number of springs having their source in the valley wash. It rises in Teton Valley in the northwest part of T. 24 N., R. 5 W., and flows roughly parallel to Teton River at a distance of one-half to three-fourths of a mile from it for about 10 or 12 miles to where it enters the main stream. Discharge measurements of Teton River have been made near Bellevue and in the vicinity of Chouteau. These are given in the following tables:

Discharge measurements of Teton River near Bellevue, Mont., 1904-1906.

Date.	Hydrographer.	Second-feet.
1904.		
November 27 ..	A. P. Porter	58
1905.		
May 8	Stockman and Porter	48
October 12	Gordon Edson	56
November 4	do	51
1906.		
April 12	G. Edson	25.2
May 9	do	43.1
June 22	Edson and Richards	17

Discharge measurements of Teton River near Chouteau, Mont., 1904-5.

Date.	Hydrographer.	Second-feet.
1904.		
November 9 ...	A. P. Porter	7.3
1905.		
May 9	Stockman and Porter	8
October 13	Gordon Edson	3
1906.		
April 13	Morse Edson	7.2
May 9	G. Edson	4.6
June 23	Edson and Richards	7.8

BELT CREEK.

This stream rises in the northern part of the Little Belt Mountains, flows north across the east-central part of the district, draining the territory lying west of the Highwood Mountains, and entering the Missouri about 12 miles northeast of Great Falls. It is a vigorous mountain stream, which carries a large flow of water in its upper course throughout all seasons of the year, especially near the mountains, but at the town of Belt all this water sinks to an underflow (see Pl. II, A) during the late summer months, leaving the stream bed dry. The loss is probably due to the fact that soft porous sandstone forms the floor of Belt Creek valley. A view of the dry

bed of Belt Creek is shown in Pl. II, A. From a short distance below the town of Belt to its mouth the stream has a small but continuous flow. Discharge measurements above the town of Belt are as follows:

Discharge measurements of Belt Creek near Belt, Mont., in 1905-6.

Date.	Hydrographer.	Second-feet.
1905.		
March 17	Porter and Bird.....	8.0
May 12.....	L. R. Stockman.....	7.8
June 11.....	A. P. Porter.....	578
1906.		
April 20.....	G. Edson.....	4.62
May 18.....	do.....	160
May 19.....	do.....	155
June 1.....	do.....	357
July 14.....	R. Richards.....	190
November 10 ..	Follansbee and Richards	3.55

OTTER CREEK.

Otter Creek is one of the largest tributaries entering Belt Creek from the east. It rises on the northeastern slope of the Little Belt Mountains near Barker and flows north for about 6 miles, thence northwest, joining Belt Creek near Armington. It receives several small spring-fed tributaries from the south, including Little Otter Creek, Bundy Coulee, Swan Coulee, and Ford Creek. Its branches from the north, which have their source in the Highwood Mountains, are Williams and Cora creeks—the former entering near Spion Kop and the latter 2 miles above its mouth. No discharge measurements have been made of Otter Creek, but it has considerable water throughout all seasons of the year, which is supplied mainly by a number of large springs along its course.

OTHER SMALL STREAMS.

The area lying between Belt Creek and Smith River is drained by Box Elder Creek and Sand Coulee. Box Elder Creek rises on the high plateaus about 3 miles west of Riceville, flows northward in a direction roughly parallel to Belt Creek, and enters the Missouri about 9 miles northeast of Great Falls. This stream carries only a small flow of water. Sand Coulee, an intermittent stream with a large drainage area, is formed by the union of several small canyon tributaries southeast of Stockett. It continues northward to a point about 6 miles below Stockett, where it makes a sharp turn to the west and meanders through a wide level-floored valley for about 7 miles, entering Missouri River about 4 miles above Great Falls. That portion of its valley through which the stream flows from the point where it makes the sharp turn to the west is a part of the preglacial valley of

the Missouri, which extends from the mouth of Sand Coulee eastward to Box Elder Creek and then northeastward to near the mouth of Belt Creek, where it reunites with the present channel.

East of Otter Creek there is a prominent ridge constituting a low divide between the Highwood and Little Belt mountains which has been named the Otter Creek divide. East of this divide the drainage is all to the northeast into Arrow Creek, which is a small tributary of the Missouri, entering a short distance above the mouth of Judith River. Arrow Creek, which has its source on the southern slope of the Highwood Mountains, flows eastward, passing out of this district in T. 18 N., R. 11 E. Its principal affluent is Surprise Creek, which rises at the base of Wolf Butte and pursues a northeasterly course, uniting with the main stream outside of the area here described. Running Wolf Creek rises higher up the slopes of the Little Belt Mountains farther to the southeast and flows northeasterly past Stanford Buttes, joining Judith River outside of the district. East of Running Wolf Creek there are several small creeks crossing the extreme southeast corner of the district which belong to the Judith River system. These are Skull, Willow, and Sage creeks.

LAKES AND SWAMPS.

The lakes occurring within the Great Falls district are of two kinds—those on the table-land, which hold flood water during a small portion of the year, and the artificial lakes, which are used as storage reservoirs for the most important irrigation systems. The largest of the natural lakes is Benton Lake, located on the highlands about 9 miles nearly due north of Great Falls. It is about 1 mile wide and 2½ miles long, and is said to have formerly held water all the year. At present the flood water which it receives during the spring sinks away, leaving the lake bed dry throughout the entire summer. It is situated in front of the terminal moraine of the Keewatin ice sheet and is probably of glacial origin. Freezeout Lake, situated in the center of an area of glacial lake deposits in Freezeout Basin, holds a small amount of water a portion of the year. There is also another small, dry lake on the plains about 3 miles southeast of Dutton. Northeast of Priest Buttes are two artificial lakes, known as Priest Lakes, which are formed by seepage water from the Cascade Land Company's canal, and south of Ralston Gap there is a small lake used as a storage reservoir. Lakes or reservoirs are of frequent occurrence throughout the district. One of considerable size is found on the table-land north of Lowry, and another, now abandoned, south of Square Butte, in the Little Muddy Creek valley. Many other smaller lakes of this character are found throughout the district, the locations of which are given on the geologic map. On Burton Bench, near

Teuchot home ranch, there are a number of small lagoons or lakes fed by springs which contain water throughout the year.

To the west of the area treated in this report and along the base of the Lewis Mountains there is a zone in which local mountain glaciers have deposited morainal material over wide districts bordering the larger streams. Throughout these glaciated areas there are innumerable small lakes and swamps which furnish water to the mountain streams crossing them.

UNDERGROUND WATERS.

GENERAL STATEMENTS.

The water-bearing rocks of the Great Falls region are confined mainly to the basal Colorado and the Kootenai formations, where a number of sandstone beds occur which are porous and imbibe water freely when conditions are favorable. There are other formations within the district that have sandstones that probably contain more or less water. These are the Eagle and Claggett sandstones of the Montana formation and the coarse-grained conglomeratic sandstone of the Ellis formation. Around the sides of Square and Fort Shaw buttes a number of small springs issue from the base of the Eagle sandstone. In the Kootenai formation several water-bearing horizons are found. The massive gray sandstone overlying the coal, which ranges in thickness from 25 to 80 feet, is the source of a number of springs along Otter Creek, and wherever the coal is mined, especially where the sandstone forms the roof, considerable difficulty is encountered with water from this formation. Above the sandstone overlying the coal there are a number of massive sandstones interbedded with red shale, which, when they occupy summits of plateaus, have numerous small springs issuing from their base. These Kootenai sandstone beds are the sources of numerous small springs wherever they are exposed from the eastern margin of the field to Smith River. West of Stockett, however, they are overlain by basal sandstones of the Colorado, which cap the plateau summits west and south of Sand Coulee, extending to beyond Missouri River and including the bench land north of Ulm. Throughout this area springs are of frequent occurrence at the base of the Colorado sandstone, and wherever well borings on the summits of the plateau have entered this sandstone a good supply of water has usually been obtained.

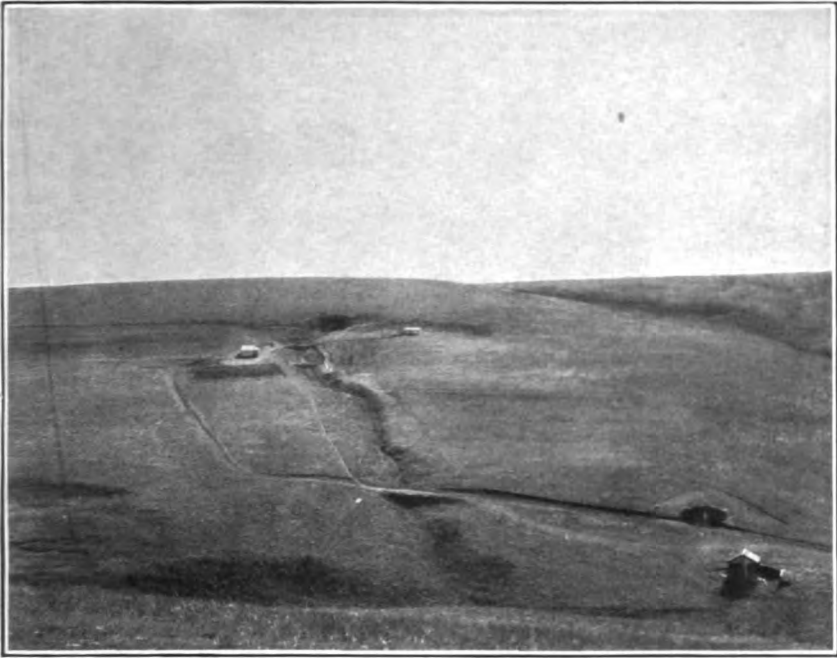
SPRINGS.

DISTRIBUTION.

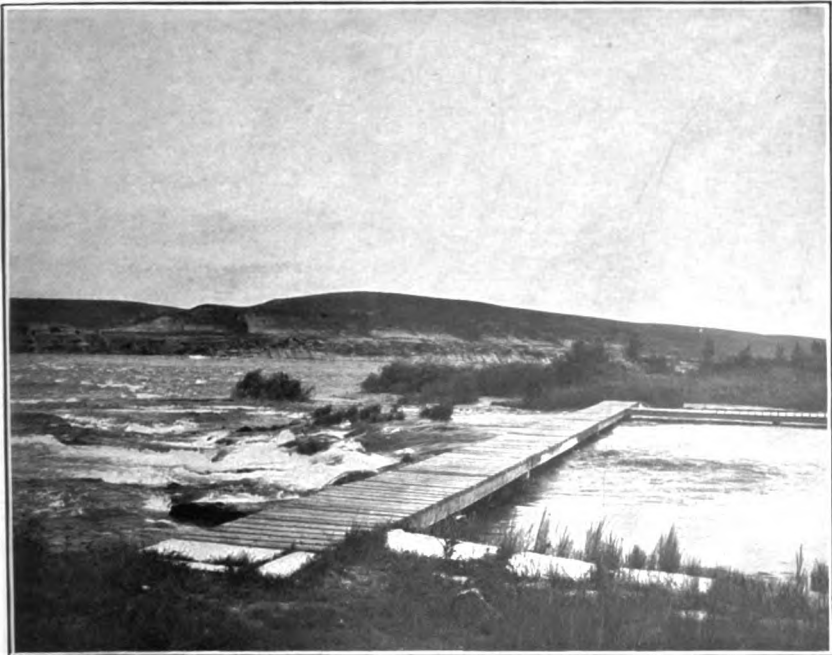
One of the most valuable sources of domestic and stock water supply in the Great Falls district is found in the numerous springs which occur along the upper courses of the smaller mountain streams

and in the valleys of the larger streams throughout the lower Plains country. Along the northern slope of the Little Belt Mountains springs are very abundant. The zone bordering the mountains is essentially a plateau region traversed by numerous mountain streams which flow through deeply cut valleys. In the bottom of these valleys and along their sides at different elevations above the streams springs of moderate flow occur at frequent intervals. Their source is the various water-bearing sandstones of the Kootenai formation, which extend southward far up the slopes to the high hilly zone bordering the mountains where there is an increased precipitation, and the sandstones absorb a large amount of water. Lower down on the plains the mountain streams cut and expose these sandstones, leaving the water free to escape as springs in the sides of the plateaus and in the lower portions of the valleys. Springs of this character are most abundant along Otter and Belt creeks, Sand Coulee, Smith River, and their principal tributaries (see Pl. V, *A*). They are usually not large, but afford a steady supply of good water when properly developed. West of Missouri River springs are less numerous. Several are found issuing from the base of the Eagle sandstone on the sides of Square and Fort Shaw buttes. At one locality on the west side of Square Butte water from a number of these small springs which have been developed is piped 2 miles to the Toman stock ranch, where it is utilized for domestic purposes (see Pl. II, *B*). On the north side of Sun River the high gravel-capped plateau is more or less dissected by canyons leading southward. In these canyons and in the heads of coulees tributary to them springs are frequent. They have their source in the gravel terrace which caps the plateau, or in the underlying Eagle sandstone. The flow, though not large, is continuous, the water being used mainly for stock purposes by the Flowerree Cattle Company. A few small springs are found along Muddy Creek of Sun River northwest of Vaughn and along the base of the bluffs at the upper end of Burton Bench.

In Sun and Teton River valleys there are a few large springs which derive their water from the underflow of these streams. Probably the largest spring of this character is found in Teton Valley about 7 miles above Chouteau, where a sufficient amount of water issues from the valley wash to supply a stream of considerable size, known as Spring Creek. In Sun River valley at Lowry is a spring of similar size, which is utilized for both irrigation and stock purposes. This spring has a large flow of excellent water, which enters Sun River a short distance below Lowry. Another spring, somewhat smaller, is found on the opposite side of the river at Skinner and Heikie's ranch, and farther down the river, a short distance above the intrusive dike which crosses Sun River valley about 1 mile west of Fort Shaw, there is a small area where numerous springs issue



A. SPRING AT BASE OF COLORADO SANDSTONE, 12 MILES SOUTH OF GREAT FALLS, MONT.



B. GIANT SPRINGS, NEAR GREAT FALLS, MONT.

from the valley wash. Springs are not infrequent in Sun River valley between Lowry and Augusta. At Sam Larkin's ranch, 6 miles below Augusta, a spring issues from the base of a low gravel-capped terrace, and has a strong flow of water throughout the year. Other springs of a similar character examined in this part of Sun River valley are given in the table on pages 42-50, with their source, quality, and approximate yield.

A few springs are found along Missouri River between Cascade and Great Falls which are used for domestic and stock purposes, although in the majority of cases in this vicinity the water supply is derived from shallow wells. Along the base of the Big Belt Mountains on the east side of the river springs are more numerous, and in many instances they have been given the chief consideration in locating ranches.

GIANT SPRINGS.

Near Great Falls are some very large springs which present unique geologic features and an interesting question as to the source of the water (see Pl. V, *B*). These springs, locally known as Giant Springs, are located on the south bank of Missouri River about 3 miles below Great Falls. They have a very large flow of relatively pure water, which appears at the surface through large joints in a medium to coarse-grained sandstone belonging to the Kootenai or lower Cretaceous rocks. On either side of the main spring for a short distance are smaller springs flowing from the joints, and directly opposite it in the bed of the river there is a large spring, which is apparent during low water. The Giant Springs were discovered by Captain Lewis, of the Lewis and Clark Expedition, in 1804, and in his description were spoken of as the "largest fountain in the United States."

According to measurements made by E. T. Nettleton ^a the flow of these springs is approximately 638 cubic feet per second, an amount which, converted into gallons, is the equivalent of over 400,000,000 gallons every twenty-four hours—a veritable underground river. The fact that the water of Giant Springs issues from rocks at the water's edge and in the bed of the river renders it difficult to measure their exact flow. In order to ascertain this amount, measurements were taken of the total flow of Missouri River above and below the springs; the difference between these two measurements is assumed to be the quantity furnished to the river by the springs. It is readily seen from the above figures that these springs rank among the largest in the United States. The water, which boils up with considerable force, is clear, blue, and relatively pure, containing no more dissolved salts than the average well water of the region. It has a temperature of about 50° F.

^a See Bibliography, p. 9.

No spring deposits occur in the immediate vicinity of Giant Springs, and the water is not generally regarded as possessing therapeutic value. It is not utilized at present, but is allowed to flow into the river. There are, however, a few improvements, such as sidewalks, etc., which make it possible for tourists to view the springs from the most advantageous points.

A chemical analysis of the water was made several years ago by James A. Dodge, of the University of Wisconsin, and a field analysis of the water was made during the past field season by W. R. Calvert. These analyses are given below.

Analyses of water of Giant Springs near Great Falls, Mont.

MINERAL ANALYSIS.

[Grains per gallon.]

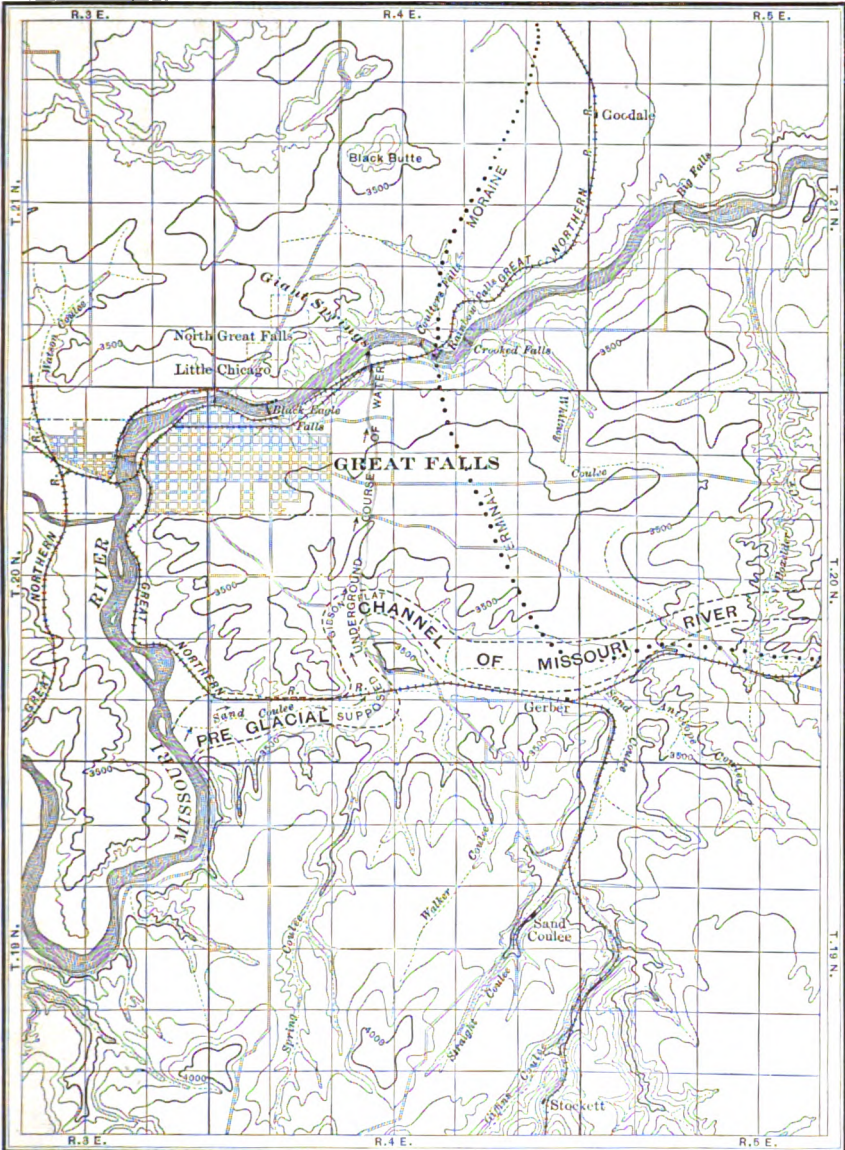
CaSO ₄	14.04
CaCO ₃	4.38
MgCO ₃	4.98
NaCl	.56
Traces of borates and potassium and lithium.	

FIELD ANALYSIS.

[Parts per million.]

Turbidity	0
Color	0
Iron	0
Calcium	Moderate.
Total hardness	97
Total alkalinity	340
Alkaline carbonates	0
Alkaline-earth carbonates	339
Sulphates	300
Chlorides	10

From a careful study of the geologic relations in the vicinity of Great Falls, it is believed by the writer that the water of Giant Springs is derived from the subriver flow of the Missouri which leaves the valley of that stream near the mouth of Sand Coulee as an underflow and passes down its preglacial channel, which extends up Sand Coulee, into Gibson Flat, an oxbow in the old river channel. From here by a subterranean passage through porous Cretaceous sandstone and sandy shale, which dip in a favorable direction for its transmission, it makes its escape to the present Missouri River, where it appears in the form of Giant Springs (see Pls. V, B, and VI). It is further believed by the writer that the jointing, which is here well developed with the major joint planes extending in a north-south direction, is an important factor in the underground movement of the water. It is also possible that a fault in this vicinity further facilitates the underground passage of the water, but no positive



MAP OF GREAT FALLS DISTRICT, MONTANA, SHOWING PREGLACIAL CHANNEL OF MISSOURI RIVER AND COURSE OF UNDERGROUND WATER.

evidence of this was seen. Well borings in lower Sand Coulee and Gibson Flat demonstrate that the materials filling the old valley are largely coarse river sediments, well adapted for rapid percolation of water.

From the above it is readily seen that along the supposed underground course of the water from the mouth of Sand Coulee to where it appears at the surface as springs, the physical conditions are such as to permit the passage of a large volume of water, an amount believed to be equivalent to that furnished by the Giant Springs.

WELLS.

While springs are the principal source of domestic water supply in the Great Falls region, there are a number of localities, especially in the larger valleys, where the greater part of such water is derived from shallow wells rarely exceeding 20 feet in depth. On the summits of some of the plateaus bordering the Little Belt Mountains, where dry farming is successfully practiced, wells obtain water at depths varying from 100 to 300 feet, depending on the locality. To the west and north of Great Falls, throughout the highland districts, wells are usually shallow, rarely being sunk below the base of the gravel terraces, which vary from 25 to 40 feet in thickness and cover extensive areas. In the larger valleys traversing the western part of the district wells are usually shallower than those on the highland, and water is more abundant. Throughout Burton Bench, north of Teton River, they vary from 20 to 100 feet, the deeper ones being artesian. A few deep wells have been dug in the vicinity of Great Falls, three by the Great Falls Meat Company on the table-land east of Great Falls, two by the Copeland Brothers near the south end of Sun River bridge, and others farther up Missouri River, one on Odell ranch and another at Ulm. The deepest boring in this portion of Montana occurs about 6 miles east of Dutton, where an oil prospect hole, known as the Banatyne well, has been sunk to a depth of 1,500 feet. Records of the Copeland Brothers, Banatyne, and Odell wells are given below, and on subsequent pages occur well tables giving the location, depth, quantity, and quality of water of a number of representative wells in the Great Falls district.

*Records of Copeland Brothers' wells near the south end of Sun River bridge,
Great Falls, Mont.*

WELL NO. 1.

	Feet.
Fine sand.....	0-4
Gumbo.....	4-15
Blue clay.....	15-31
Sand and gravel, water bearing.....	31-33
Red sandstone.....	33-43

*Records of Copeland Brothers' wells near the south end of Sun River bridge,
Great Falls, Mont—Continued.*

WELL NO. 1—Continued.

	Feet.
Ferruginous sandstone.....	43- 47
Blue shale.....	47- 59
Gray shale.....	59- 85
Gray sandy rock.....	85-100
Light-red rock.....	100-105
Dark-red rock.....	105-112
Gray compact sandstone.....	112-122
Blue shale.....	122-134
Red rock.....	134-144
Sandstone with shaly layers.....	144-147
Light-red rock.....	147-157
Soapstone.....	157-227
Impure sandstone.....	227-229
Gray shale.....	229-244
Impure sandstone.....	244-247
Gray shale.....	247-252
Impure sandstone.....	252-255
Gray shale.....	255-263
Impure sandstone.....	263-265
Gray shale.....	265-277
Sandstone and shale.....	277-282

WELL NO. 2.

Fine sand.....	0- 8
Medium fine sand.....	8- 25
Gumbo.....	25- 36
Blue clay.....	36- 52
Red rock.....	52- 62
Ferruginous sandstone.....	62- 66
Blue shale.....	66- 81
Red rock.....	81-103
Fine gray sandstone.....	103-107
Light-red rock.....	107-123
Blue shale.....	123-131
Gray sandstone.....	131-143
Brown shale.....	143-157
Gray shale.....	157-167
Soapstone.....	167-207
Light-red rock.....	207-219
Impure sandstone.....	219-223
Dark-red rock.....	223-233
Black shale.....	233-247
Light-red rock.....	247-250
Gray shale.....	250-260
Impure sandstone.....	260-263
Gray shale.....	263-265
Impure sandstone.....	265-266
Blue shale.....	266-274
Impure sandstone.....	274-276

*Records of Copeland Brothers' wells near the south end of Sun River bridge,
Great Falls, Mont—Continued.*

WELL NO. 2—Continued.

	Feet.
Dark shale.....	276-280
Impure sandstone.....	280-283
Gray shale.....	283-289
Blue sandstone.....	289-297
Brown shale.....	297-300
Blue sandstone.....	300-310
Impure limestone.....	310-318
White limestone.....	318-370
Brown limestone.....	370-417
White limestone.....	417-459
Blue limestone.....	459-519
Impure limestone.....	519-541
Brown limestone.....	541-569
Blue limestone.....	569-581
White limestone.....	581-643

Record of Banatyne well, 6 miles east of Dutton, Mont.

	Feet.
Yellow clay.....	0- 74
Shale.....	74- 280
Sand, containing salt water and gas.....	280- 285
Sandy shale.....	285- 358
Black sand.....	358- 365
Shale.....	365- 500
Sand, containing salt water.....	500- 509
Sand and gritty shale.....	509- 605
Soft, white conglomerate.....	605- 780
Hard conglomerate.....	780- 870
Fine blue sand.....	870- 880
Hard blue shale.....	880- 900
Hard shale in thin layers.....	900- 950
Dark-blue shale.....	950- 975
Black shale.....	975-1,040
Hard bluish sandstone.....	1,040-1,130
Black shale.....	1,130-1,160
Red limestone.....	1,160-1,200
Red sandstone.....	1,200-1,240

It is believed that the so-called red limestone encountered at a depth of 1,160 feet below the surface represents the upper part of the Kootenai formation.

Record of Odell well in Missouri River, south of Great Falls, Mont.

	Feet.
Alluvium.....	0- 20
Sand.....	20-145
Clay.....	145-205
Gravel.....	205-212

Partial list of springs of Great Falls region, Montana.

No.	County.	Locality.	Township, etc.	Owner.	Tem- pera- ture.	Quan- tity.	Material from which spring issues.	Approxi- mate eleva- tion.	Is supply con- tinu- ous?	Use.
1	Teton.	Chouteau.	SW $\frac{1}{4}$ sec. 30, T. 25 N., R. 5 W.	On Government land.	° F.	Small.	Blue shale.	Feet.		Stock.
2	do.	do.	NE $\frac{1}{4}$ sec. 18, T. 25 N., R. 5 W.	Frank Ralston.	52	do.	do.	4,100	Yes.	Domestic and stock.
3	do.	do.	SW $\frac{1}{4}$ sec. 28, T. 24 N., R. 5 W.	On Government land.	52	do.	Sandstone.	4,100	Yes.	Stock.
4	do.	do.	SW $\frac{1}{4}$ sec. 1, T. 24 N., R. 4 W.	H. R. Thompson.	50	do.	Alluvium.	4,050	Yes.	Domestic and stock.
5	do.	do.	SE $\frac{1}{4}$ sec. 24, T. 23 N., R. 5 W.	do.	50	do.	Blue shale.	3,900	Yes.	Domestic and stock.
6	do.	do.	SE $\frac{1}{4}$ sec. 20, T. 23 N., R. 4 W.	P. Grossen.	52	Medium.	Sandstone.	4,200	Yes.	Domestic, stock, and irrigation.
7	do.	do.	SW $\frac{1}{4}$ sec. 18, T. 23 N., R. 4 W.	S. T. Cattle Co.	53	Small.	do.	3,950	Yes.	Stock.
8	Cascade.	do.	NW $\frac{1}{4}$ sec. 13, T. 22 N., R. 4 W.	J. Thorn.	55					Do.
9	do.	Augusta.	SW $\frac{1}{4}$ sec. 28, T. 22 N., R. 4 W.	Flowersee.	55				Yes.	Do.
10	Lewis and Clark.	do.	NW $\frac{1}{4}$ sec. 26, T. 21 N., R. 6 W.	Jim Lytle.				4,300	No.	
11	do.	do.	Sec. 13, T. 21 N., R. 6 W.	Flowersee.	48					
12	do.	do.	NW $\frac{1}{4}$ sec. 35, T. 21 N., R. 5 W.	Clark Lytle.						
13	Cascade.	do.	NE $\frac{1}{4}$ sec. 2, T. 21 N., R. 5 W.	do.						
14	do.	do.	NE $\frac{1}{4}$ sec. 6, T. 21 N., R. 4 W.	Flowersee.						
15	Lewis and Clark.	do.	SE $\frac{1}{4}$ sec. 2, T. 20 N., R. 6 W.	P. Mayer.	52	Small.		4,000	No.	Do.
16	do.	do.	NE $\frac{1}{4}$ sec. 1, T. 20 N., R. 6 W.	C. C. Woods.	54			4,000	Yes.	Irrigation.
17	do.	do.	NW $\frac{1}{4}$ sec. 1, T. 20 N., R. 5 W.	S. Larkin.	52	Small.		4,100		
18	do.	do.	SE $\frac{1}{4}$ sec. 7, T. 20 N., R. 5 W.	J. S. Lytle.				4,000	Yes.	
19	do.	do.	SE $\frac{1}{4}$ sec. 9, T. 20 N., R. 5 W.	P. Bickle.	54	Small.		4,000	Yes.	
20	Cascade.	do.	NW $\frac{1}{4}$ sec. 5, T. 20 N., R. 4 W.	Flowersee.	51	Small.			Yes.	Domestic and stock.
21	do.	Hepler.	NE $\frac{1}{4}$ sec. 13, T. 21 N., R. 4 W.	do.	52	do.			Yes.	Do.
22	do.	do.	SW $\frac{1}{4}$ sec. 14, T. 21 N., R. 4 W.	do.	48	Medium.	Blue shale.		Yes.	Do.
23	do.	do.	NW $\frac{1}{4}$ sec. 35, T. 22 N., R. 4 W.	do.	52					
24	do.	do.	NE $\frac{1}{4}$ sec. 27, T. 22 N., R. 4 W.	do.						
25	do.	do.	NE $\frac{1}{4}$ sec. 2, T. 20 N., R. 4 W.	do.						
26	do.	do.	NE $\frac{1}{4}$ sec. 4, T. 20 N., R. 3 W.	do.						
27	do.	do.	NE $\frac{1}{4}$ sec. 10, T. 20 N., R. 3 W.	D. B. Todd.		Medium.	Alluvium.		Yes.	Domestic and stock.
28	do.	do.	NE $\frac{1}{4}$ sec. 35, T. 20 N., R. 3 W.	Carl Machel.	48	do.	do.		Yes.	Stock.
29	do.	do.	NW $\frac{1}{4}$ sec. 5, T. 20 N., R. 2 W.	On Government land.	52	do.	Blue sandstone.	3,500	Yes.	
30	do.	do.	NE $\frac{1}{4}$ sec. 20, T. 20 N., R. 2 W.	do.		Small.			Yes.	Do.
31	do.	do.	NW $\frac{1}{4}$ sec. 20, T. 20 N., R. 2 W.	do.		do.			Yes.	Do.
32	do.	do.	SE $\frac{1}{4}$ sec. 4, T. 19 N., R. 3 W.	Carl Machel.		Small.	Sandstone.		Yes.	Stock and irrigation.
33	do.	Sun River.	SW $\frac{1}{4}$ sec. 33, T. 22 N., R. 1 E.	Land Co.						
34	do.	do.	SE $\frac{1}{4}$ sec. 34, T. 21 N., R. 2 W.	On Government land.	50	Medium.			Yes.	Do.
35	do.	do.	NE $\frac{1}{4}$ sec. 35, T. 20 N., R. 2 W.	Toman Bros.		do.			Yes.	Do.

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Partial list of springs of Great Falls region, Montana—Continued.

No.	County.	Locality.	Township. etc.	Owner.	Temperature.	Quantity.	Material from which spring issues.	Approximate elevation.	Is supply continuous?	Use.
82	Cascade	Great Falls.	SW $\frac{1}{2}$ sec. 7, T. 19 N., R. 4 E.	Dudley Crothers.	° F.	Medium	Sandstone.	Feet.	Yes.	Domestic and stock.
83	do.	do.	S. $\frac{1}{2}$ sec. 14, T. 19 N., R. 5 E.	M. E. Abernathy.						
84	do.	do.	Sec. 11, T. 19 N., R. 5 E.	J. Johnston.						
85	do.	do.	NW $\frac{1}{2}$ sec. 12, T. 19 N., R. 5 E.	D. E. Johnston.						
86	do.	do.	NW $\frac{1}{2}$ sec. 7, T. 19 N., R. 5 E.	J. G. Ernst.						
87	do.	Stockett.	Sec. 35, T. 19 N., R. 4 E.	Eric Erickson.						
88	do.	do.	SW $\frac{1}{2}$ sec. 27, T. 19 N., R. 4 E.	T. Littlejohn.						
89	do.	do.	SW $\frac{1}{2}$ sec. 33, T. 19 N., R. 4 E.	John Edstrom.						
90	do.	do.	NE $\frac{1}{2}$ sec. 31, T. 19 N., R. 4 E.	L. R. Howard.						
91	do.	do.	Sec. 25, T. 19 N., R. 5 E.	T. E. Kent.						
92	do.	do.	NW $\frac{1}{2}$ sec. 36, T. 19 N., R. 5 E.	W. Turner.	Medium	Small	Sandstone.	Do.	Yes.	Domestic and stock.
93	do.	do.	SE $\frac{1}{2}$ sec. 35, T. 19 N., R. 5 E.	A. Santachi.						
94	do.	do.	Sec. 24, T. 19 N., R. 5 E.	S. C. King.						
95	do.	do.	NE $\frac{1}{2}$ sec. 27, T. 19 N., R. 5 E.	D. Lane.						
96	do.	do.	NE $\frac{1}{2}$ sec. 22, T. 19 N., R. 5 E.	do.						
97	do.	do.	SW $\frac{1}{2}$ sec. 27, T. 19 N., R. 5 E.	Benj. Stephens.						
98	do.	do.	NE $\frac{1}{2}$ sec. 2, T. 18 N., R. 4 E.	G. H. Lindh.						
99	do.	do.	NE $\frac{1}{2}$ sec. 22, T. 18 N., R. 4 E.	N. Frank.						
100	do.	do.	Sec. 28, T. 18 N., R. 4 E.	John Gillis.						
101	do.	do.	SE $\frac{1}{2}$ sec. 26, T. 18 N., R. 4 E.	do.	Medium	Small	Sandstone.	Do.	Yes.	Domestic and stock.
102	do.	do.	do.	Ed. Connelly.						
103	do.	do.	NW $\frac{1}{2}$ sec. 15, T. 18 N., R. 4 E.	C. Cavanaugh.						
104	do.	do.	Sec. 25, T. 18 N., R. 4 E.	Davale Culberson.						
105	do.	do.	SE $\frac{1}{2}$ sec. 14, T. 18 N., R. 4 E.	Eric Lindquist.						
106	do.	do.	NW $\frac{1}{2}$ sec. 25, T. 18 N., R. 5 E.	Cottonwood Coal Co.						
107	do.	do.	SW $\frac{1}{2}$ sec. 6, T. 18 N., R. 5 E.	Joe Sarlin.						
108	do.	do.	Sec. 7, T. 18 N., R. 5 E.	Joe Kornowald.						
109	do.	do.	Sec. 19, T. 18 N., R. 5 E.	A. Keels.						
110	do.	do.	NE $\frac{1}{2}$ sec. 2, T. 18 N., R. 5 E.	J. H. Betts.						
111	do.	do.	SW $\frac{1}{2}$ sec. 2, T. 17 N., R. 4 E.	J. P. Heber.	Large	Medium	Sandstone.	Do.	Yes.	Domestic.
112	do.	do.	SE $\frac{1}{2}$ sec. 2, T. 17 N., R. 4 E.	J. O. Selstrom.						
113	do.	do.	Sec. 1, T. 17 N., R. 4 E.	do.						
114	do.	do.	Sec. 17, T. 17 N., R. 4 E.	L. Herbolzheimer.						
115	do.	do.	NE $\frac{1}{2}$ sec. 21, T. 17 N., R. 4 E.	Herman Johnson.						
116	do.	do.	NW $\frac{1}{2}$ sec. 20, T. 17 N., R. 4 E.	John Pilgrim.						
117	do.	do.	Sec. 17, T. 17 N., R. 4 E.	Edwin Melsenbach.						
118	do.	do.	SW $\frac{1}{2}$ sec. 4, T. 17 N., R. 4 E.	Wm. Kirby.						
119	do.	do.	Sec. 9, T. 17 N., R. 4 E.	do.						
120	do.	do.	NE $\frac{1}{2}$ sec. 35, T. 21 N., R. 6 E.	P. P. Buchanan.						
121	do.	do.	Sec. 2, T. 20 N., R. 6 E.	V. P. Carr.	Large	do.	Sandstone.	Do.	No.	Domestic.
122	do.	do.	Sec. 35, T. 20 N., R. 6 E.	P. P. Buchanan.						
123	do.	do.	NW $\frac{1}{2}$ sec. 33, T. 20 N., R. 6 E.	Mack Derew.	55	Small	Sandstone.	Do.	Yes.	Stock.

124	do.	Sec. 32, T. 19 N., R. 6 E.	E. Turner	Medium		Domestic and stock.
125	do.	NW $\frac{1}{4}$ sec. 14, T. 19 N., R. 6 E.	John Wright	do.		Domestic.
126	do.	SW $\frac{1}{4}$ sec. 1, T. 19 N., R. 6 E.	W. S. Sifford	do.		Domestic and stock.
127	do.	NW $\frac{1}{4}$ sec. 8, T. 19 N., R. 6 E.	— Erickson	do.		Domestic.
128	do.	NE $\frac{1}{4}$ sec. 22, T. 19 N., R. 6 E.	C. Turner	Small		Do.
129	do.	SE $\frac{1}{4}$ sec. 32, T. 19 N., R. 6 E.	— Rush	Medium	3,700	Domestic and stock.
130	do.	Sec. 5, T. 19 N., R. 6 E.	W. H. Porter	do.		Do.
131	do.	Sec. 8, T. 19 N., R. 6 E.	G. Erickson	Large	3,900	Do.
132	do.	SW $\frac{1}{4}$ sec. 3, T. 19 N., R. 6 E.	Joe Bognor	Medium	4,300 (?)	Do.
133	do.	NW $\frac{1}{4}$ sec. 5, T. 19 N., R. 6 E.	J. B. Burrows	Small	3,900	Domestic.
134	do.	NW $\frac{1}{4}$ sec. 1, T. 19 N., R. 6 E.	A. Bloom	Medium		Domestic and stock.
135	do.	NW $\frac{1}{4}$ sec. 36, T. 19 N., R. 6 E.	A. H. McMillan	Small		Do.
136	do.	NE $\frac{1}{4}$ sec. 35, T. 19 N., R. 6 E.	Edgar Mann	do.		Stock.
137	do.	Sec. 36, T. 18 N., R. 6 E.	G. Siegling	Medium		
138	do.	NW $\frac{1}{4}$ sec. 19, T. 18 N., R. 6 E.	J. Eckerson	Small		Domestic and stock.
139	do.	NW $\frac{1}{4}$ sec. 19, T. 18 N., R. 6 E.	J. Shannon	Medium		Stock.
140	do.	Sec. 19, T. 18 N., R. 6 E.	J. F. Irwin	54		
141	do.	Sec. 2, T. 18 N., R. 6 E.	S. S. Crane	Small	55	Stock, domestic, and irrigation.
142	do.	SW $\frac{1}{4}$ sec. 3, T. 18 N., R. 6 E.	do.	52		
143	do.	NE $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 22, T. 18 N., R. 6 E.	Neal Creek Cattle Co.			
144	do.	NE $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 27, T. 18 N., R. 6 E.	do.			
145	do.	NE $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 33, T. 18 N., R. 6 E.	O. V. Jacobs	46		
146	do.	do.	do.	46		
147	do.	SE $\frac{1}{4}$ sec. 13, T. 18 N., R. 6 E.	J. Wiegand	Small		Domestic and stock.
148	do.	do.	do.	Medium		Irrigation.
149	do.	SE $\frac{1}{4}$ sec. 24, T. 18 N., R. 6 E.	N. Neumeier	47		Domestic.
150	do.	NW $\frac{1}{4}$ sec. 18, T. 18 N., R. 7 E.	C. Ashewert	do.	3,700	Domestic and stock.
151	do.	SE $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 30, T. 18 N., R. 7 E.	F. J. Ober	do.	3,900	Stock.
152	do.	SW $\frac{1}{4}$ sec. 31, T. 18 N., R. 7 E.	A. Albright	do.		Do.
153	do.	Sec. 27, T. 18 N., R. 7 E.	J. W. Blythe	do.		Irrigation.
154	do.	NE $\frac{1}{4}$ sec. 6, T. 18 N., R. 7 E.	John Hunter	Medium		Domestic.
155	do.	NW $\frac{1}{4}$ SW $\frac{1}{4}$ sec. 8, T. 18 N., R. 7 E.	T. D. Joseelyn	do.	3,900	Domestic and stock.
156	do.	do.	do.	do.		Stock.
157	do.	SW $\frac{1}{4}$ SW $\frac{1}{4}$ sec. 8, T. 18 N., R. 7 E.	do.	Small		Do.
158	do.	SE $\frac{1}{4}$ SW $\frac{1}{4}$ sec. 8, T. 18 N., R. 7 E.	do.	do.		Do.
159	do.	NW $\frac{1}{4}$ SW $\frac{1}{4}$ sec. 16, T. 18 N., R. 7 E.	W. B. S. Armstrong	do.		Do.
160	do.	SW $\frac{1}{4}$ SW $\frac{1}{4}$ sec. 16, T. 18 N., R. 7 E.	do.	do.		Do.
161	do.	SE $\frac{1}{4}$ sec. 16, T. 18 N., R. 7 E.	do.	do.		Do.
162	do.	NW $\frac{1}{4}$ SW $\frac{1}{4}$ sec. 22, T. 18 N., R. 7 E.	do.	Medium		Do
163	do.	NE $\frac{1}{4}$ SW $\frac{1}{4}$ sec. 22, T. 18 N., R. 7 E.	P. P. Rector	do.		Do
164	do.	NE $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 34, T. 18 N., R. 7 E.	J. W. Blythe	do.		Domestic, stock, and garden.
	do.	do.	do.	do.		Stock.

Partial list of springs of Great Falls region, Montana—Continued.

No.	County.	Locality.	Township, etc.	Owner.	Tem- pera- ture.	Quan- tity.	Material from which spring issues.	Approx- imate eleva- tion.	Is supply contin- uous?	Use.
165	Cascade	Stockett.	SE $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 34, T. 18 N., R. 7 E.	J. W. Blythe.	° F.	Medium.		Pect.	Yes.	Stock.
166	do	do	NE $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 34, T. 18 N., R. 7 E.	do.		do.			Yes.	Domestic and stock.
167	do	do	NW $\frac{1}{4}$ SW $\frac{1}{4}$ sec. 27, T. 18 N., R. 7 E.	do.		do.			Yes.	Domestic.
168	do	do	NW $\frac{1}{4}$ sec. 21, T. 18 N., R. 7 E.	T. Armstrong.		do.	Sandstone.	3,900	Yes.	Domestic and stock.
169	do	do	NW $\frac{1}{4}$ NW $\frac{1}{4}$ sec. 10, T. 18 N., R. 7 E.	G. W. Blake.		Small.		4,050	Yes.	Domestic.
170	do	do	SE $\frac{1}{4}$ NW $\frac{1}{4}$ sec. 10, T. 18 N., R. 7 E.	do.		do.		4,050	Yes.	Do.
171	do	do	SW $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 4, T. 18 N., R. 7 E.	F. Falls.		Medium.		4,025	Yes.	Stock.
172	do	do	SW $\frac{1}{4}$ SW $\frac{1}{4}$ sec. 4, T. 18 N., R. 7 E.	do.		Small.			Yes.	Domestic and stock.
173	do	do	SW $\frac{1}{4}$ NW $\frac{1}{4}$ sec. 4, T. 18 N., R. 7 E.	J. Ham.		Medium.			Yes.	Domestic and irri- gation.
174	do	do	SE $\frac{1}{4}$ NW $\frac{1}{4}$ sec. 4, T. 18 N., R. 7 E.	do.		Small.			Yes.	Stock.
175	do	do	NW $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 4, T. 18 N., R. 7 E.	do.		do.			Yes.	Do.
176	do	do	NW $\frac{1}{4}$ sec. 6, T. 18 N., R. 7 E.	Chas. Ashwort.		do.			Yes.	Domestic and stock.
177	do	do	do	do.		do.		3,800	Yes.	Stock.
178	do	do	do	do.		do.		3,800	Yes.	Do.
179	do	do	do	L. Bain.		Medium.		4,000	Yes.	Domestic.
180	do	do	do	do.		do.		4,000	Yes.	Stock.
181	do	do	SW $\frac{1}{4}$ sec. 5, T. 18 N., R. 7 E.	D. Maussa.		Large.			Yes.	Do.
182	do	do	SE $\frac{1}{4}$ sec. 34, T. 18 N., R. 8 E.	S. Colarchik.	48	Medium.			Yes.	Domestic and stock.
183	do	do	NE $\frac{1}{4}$ sec. 34, T. 18 N., R. 8 E.	J. H. Vealey.	50	Small.			Yes.	Do.
184	do	do	NW $\frac{1}{4}$ sec. 35, T. 18 N., R. 8 E.	J. Morrison.	47	Large.			Yes.	Do.
185	do	do	SW $\frac{1}{4}$ sec. 23, T. 18 N., R. 8 E.	R. Johnson.	51	Medium.			Yes.	Do.
186	do	do	NW $\frac{1}{4}$ sec. 22, T. 18 N., R. 8 E.	A. A. Dawson.		Small.			No.	Stock.
187	do	do	NE $\frac{1}{4}$ sec. 23, T. 18 N., R. 8 E.	do.	61	do.			Yes.	Domestic.
188	do	do	SW $\frac{1}{4}$ sec. 14, T. 18 N., R. 8 E.	J. Magnuson.	51	do.			Yes.	Stock.
189	do	do	NW $\frac{1}{4}$ sec. 14, T. 18 N., R. 8 E.	do.		do.			Yes.	Do.
190	do	do	SW $\frac{1}{4}$ sec. 10, T. 18 N., R. 8 E.	W. McGinnis.		do.			Yes.	Do.
191	do	do	NE $\frac{1}{4}$ sec. 11, T. 18 N., R. 8 E.	M. Owen.		do.			Yes.	Do.
192	do	do	NE $\frac{1}{4}$ sec. 16, T. 18 N., R. 8 E.	P. Brown.	49	Medium.			Yes.	Domestic and stock.
193	do	do	NE $\frac{1}{4}$ sec. 13, T. 18 N., R. 8 E.	I. Cameron.		Small.			No.	Stock.
194	do	do	NW $\frac{1}{4}$ sec. 26, T. 18 N., R. 8 E.	R. Johnson.		Medium.			Yes.	Do.
195	do	do	NW $\frac{1}{4}$ NW $\frac{1}{4}$ sec. 21, T. 18 N., R. 8 E.	S. Anderson.					Yes.	Domestic and stock.

196	do.	do.	NE. $\frac{1}{2}$ sec. 21, T. 18 N., R. 8 E.	do.	do.	do.	Yes.	Do.
197	do.	do.	SW. $\frac{1}{2}$ sec. 28, T. 18 N., R. 8 E.	do.	R. Williamson.	Medium	No.	Do.
198	do.	do.	NE. $\frac{1}{2}$ sec. 7, T. 18 N., R. 8 E.	do.	— Klein.	Small		Stock.
199	do.	do.	Sec. 31, T. 18 N., R. 8 E.	do.	A. Owen.		Yes.	Domestic and stock Do.
200	do.	do.	NW. $\frac{1}{2}$ sec. 16, T. 18 N., R. 8 E.	do.	P. Brown.	Medium	50	Stock.
201	do.	do.	SE. $\frac{1}{2}$ sec. 16, T. 18 N., R. 8 E.	do.	do.	Medium	49	Domestic and stock Do.
202	do.	do.	SW. $\frac{1}{2}$ sec. 23, T. 18 N., R. 8 E.	do.	F. J. Ober.	do.	Yes.	Stock.
203	do.	do.	NW. $\frac{1}{2}$ sec. 21, T. 18 N., R. 8 E.	do.	S. Anderson.	Small	Yes.	Domestic and stock Do.
204	do.	do.	R. 8 E.	do.	A. Owen.		Yes.	Domestic.
205	do.	do.	SE. $\frac{1}{2}$ sec. 16, T. 18 N., R. 8 E.	do.	P. Brown.	Large	49	Domestic and stock.
206	do.	do.	NE. $\frac{1}{2}$ sec. 2, T. 17 N., R. 7 E.	do.	McConkey Bros.	Small		Stock.
207	do.	do.	SW. $\frac{1}{2}$ sec. 12, T. 17 N., R. 7 E.	do.	do.	do.	Yes.	Do.
208	do.	do.	NW. $\frac{1}{2}$ sec. 1, T. 17 N., R. 7 E.	do.	G.W. Goodman.	do.	Yes.	Do.
209	do.	do.	SW. $\frac{1}{2}$ sec. 1, T. 17 N., R. 6 E.	do.	Peter Johnson.	Medium		Garden irrigation.
210	do.	do.	NW. $\frac{1}{2}$ sec. 16, T. 17 N., R. 6 E.	do.	do.			
211	do.	do.	SW. $\frac{1}{2}$ sec. 16, T. 17 N., R. 6 E.	do.	do.			
212	do.	do.	SE. $\frac{1}{2}$ sec. 9, T. 17 N., R. 6 E.	do.	F. Skelton.	Medium		
213	do.	do.	SW. $\frac{1}{2}$ sec. 31, T. 17 N., R. 7 E.	do.	C. P. Nelsman.			
214	do.	do.	SW. $\frac{1}{2}$ sec. 24, T. 17 N., R. 7 E.	do.	Peterson & Johnson.	Medium	5,000	Domestic and stock.
215	do.	do.	Sec. 22, T. 17 N., R. 7 E.	do.	B. W. Armstrong.	do.		
216	do.	do.	Sec. 15, T. 17 N., R. 7 E.	do.	N. Montag.	do.		
217	do.	do.	SW. $\frac{1}{2}$ sec. 15, T. 17 N., R. 7 E.	do.	J. Holmberg.	Small		
218	do.	do.	SE. $\frac{1}{2}$ sec. 30, T. 17 N., R. 7 E.	do.	Bundy & Henderliden.	Medium		Stock.
219	do.	do.	NE. $\frac{1}{2}$ sec. 36, T. 17 N., R. 7 E.	do.	do.	Limestone		
220	do.	do.	Sec. 25, T. 17 N., R. 7 E.	do.	do.			
221	do.	do.	Sec. 19, T. 17 N., R. 8 E.	do.	P. McFee.			
222	do.	do.	SW. $\frac{1}{2}$ sec. 36, T. 17 N., R. 7 E.	do.	Bundy & Henderliden.	Large	4,900	Do.
223	do.	do.	SE. $\frac{1}{2}$ sec. 25, T. 17 N., R. 7 E.	do.	Hanson Bros.	Limestone		
224	do.	do.	SE. $\frac{1}{2}$ sec. 29, T. 17 N., R. 8 E.	do.	P. Dotseth.	Shale		
225	do.	do.	NE. $\frac{1}{2}$ sec. 32, T. 17 N., R. 8 E.	do.	Bundy & Henderliden.	Small	4,500	Do.
226	do.	do.	NE. $\frac{1}{2}$ sec. 19, T. 17 N., R. 8 E.	do.	Bundy & Henderliden.	Medium		Do.
227	do.	do.	NW. $\frac{1}{2}$ sec. 4, T. 17 N., R. 8 E.	do.	— Peterson.	Sandstone	50	Do.
228	do.	do.	Sec. 5, T. 17 N., R. 8 E.	do.	E. R. Huggins.	Medium	No.	Do.
229	do.	do.	SE. $\frac{1}{2}$ sec. 18, T. 17 N., R. 8 E.	do.	McConkey Bros.	Medium	Yes.	
230	do.	do.	R. 8 E.	do.	do.			
231	do.	do.	NE. $\frac{1}{2}$ sec. 18, T. 17 N., R. 8 E.	do.	Ed. Landy.			
232	do.	Geyser.	SE. $\frac{1}{2}$ sec. 34, T. 18 N., R. 8 E.	do.	S. Colarchik.		49	Yes.
233	do.	do.	NE. $\frac{1}{2}$ sec. 34, T. 18 N., R. 8 E.	do.	J. H. Vasey.	Large	47	Yes.
234	do.	do.	NW. $\frac{1}{2}$ sec. 35, T. 18 N., R. 8 E.	do.	J. Morrison.	Sandstone	52	Yes.
235	do.	do.	SW. $\frac{1}{2}$ sec. 23, T. 18 N., R. 8 E.	do.	R. Johnson.	do.		
236	do.	do.	N. E. $\frac{1}{2}$ sec. 22, T. 18 N., R. 8 E.	do.	A. A. Dawson.	Small	61	Domestic and stock Do.
237	do.	do.	do.	do.	do.	do.	4,000	Not used.
	do.	do.	SW. $\frac{1}{2}$ sec. 3, T. 18 N., R. 8 E.	do.	C. W. McClay.	Large	50	Yes.

Partial list of springs of Great Falls region, Montana—Continued.

No.	County.	Locality.	Township, etc.	Owner.	Temperature.	Quantity.	Material from which spring issues.	Approximate elevation.	Is supply continuous?	Use.
238	Cascade	Geyser	NE $\frac{1}{2}$ sec. 11, T. 18 N., R. 8 E.	M. Owen	52	Small		Feet.	Yes	Stock.
239	do.	do.	NW $\frac{1}{2}$ sec. 14, T. 18 N., R. 8 E.	J. Magnuson	52	Small	Fine sand.		Yes	Do.
240	do.	do.	NE $\frac{1}{2}$ sec. 11, T. 18 N., R. 8 E.	Martin Owen		Medium	Sand rock		Yes	Do.
241	do.	do.	NW $\frac{1}{2}$ sec. 10, T. 18 N., R. 8 E.	Geo. Hay		Small			Yes	Do.
242	do.	do.	SE $\frac{1}{2}$ sec. 13, T. 18 N., R. 8 E.	W. McGinnis	52	Medium	Shale		Yes	Do.
243	do.	do.	SW $\frac{1}{2}$ sec. 14, T. 18 N., R. 9 E.	W. Kernaghan		do.	Sandstone		Yes	Do.
244	do.	do.	NW $\frac{1}{2}$ sec. 20, T. 18 N., R. 9 E.	J. Kernaghan	46	Small			Yes	Do.
245	do.	do.	SE $\frac{1}{2}$ sec. 9, T. 18 N., R. 9 E.	C. J. Ellis		do.			Yes	Do.
246	do.	do.	SE $\frac{1}{2}$ sec. 13, T. 18 N., R. 9 E.	J. Strong	46	Medium			Yes	Do.
247	do.	do.	SE $\frac{1}{2}$ sec. 13, T. 18 N., R. 9 E.	J. Armstrong		do.			Yes	Do.
248	do.	do.	SE $\frac{1}{2}$ sec. 9, T. 18 N., R. 9 E.	C. J. Ellis	48	do.		4, 100	Yes	Domestic, stock, and irrigation.
249	do.	do.	Sec. 12, T. 18 N., R. 9 E.	S. C. Philbrick		do.		4, 200	Yes	Do.
250	do.	do.	SE $\frac{1}{2}$ sec. 20, T. 18 N., R. 9 E.	D. Rankin		Medium			Yes	Stock.
251	do.	do.	NW $\frac{1}{2}$ sec. 30, T. 18 N., R. 9 E.	School section.		do.			Yes	Do.
252	do.	do.	SE $\frac{1}{2}$ sec. 16, T. 18 N., R. 9 E.	J. B. Lone		Small			Yes	Domestic and stock.
253	do.	do.	SE $\frac{1}{2}$ sec. 16, T. 18 N., R. 9 E.	J. Kernaghan		do.			Yes	Stock.
254	do.	do.	SW $\frac{1}{2}$ sec. 13, T. 18 N., R. 9 E.	do.		do.			Yes	Do.
255	do.	do.	Sec. 32, T. 18 N., R. 10 E.	J. R. Long	15	Small			Yes	Domestic.
256	do.	do.	SW $\frac{1}{2}$ sec. 17, T. 18 N., R. 10 E.	J. Keto		Medium		3, 800	Yes	Stock and garden.
257	do.	do.	NW $\frac{1}{2}$ sec. 3, T. 17 N., R. 8 E.	J. Larson	48	do.	Sandstone	3, 700	Yes	Stock.
258	do.	do.	SW $\frac{1}{2}$ sec. 3, T. 17 N., R. 8 E.	C. W. McClay	54	Medium	do.		Yes	Do.
259	do.	do.	SE $\frac{1}{2}$ sec. 11, T. 17 N., R. 8 E.	W. A. Nelson	55	Medium			No	Do.
260	do.	do.	NE $\frac{1}{2}$ sec. 14, T. 17 N., R. 8 E.	do.	54	Small			No	Do.
261	do.	do.	NE $\frac{1}{2}$ sec. 18, T. 17 N.	G. L. Lee	54	do.			No	Do.
262	do.	do.	R. 9 E.	do.	54	do.			No	Do.
263	do.	do.	NW $\frac{1}{2}$ SE $\frac{1}{2}$ sec. 18, T. 17 N.	do.	54	do.			No	Do.
264	do.	do.	SW $\frac{1}{2}$ SE $\frac{1}{2}$ sec. 18, T. 17 N.	do.	49	Medium			Yes	Do.
265	do.	do.	NE $\frac{1}{2}$ SE $\frac{1}{2}$ sec. 27, T. 17 N.	S. McAllister	47	do.			Yes	Do.
266	do.	do.	NE $\frac{1}{2}$ SE $\frac{1}{2}$ sec. 26, T. 17 N.	do.	45	Large			Yes	Domestic and stock.
267	do.	do.	SW $\frac{1}{2}$ NE $\frac{1}{2}$ sec. 35, T. 17 N.	G. Okerman	44	Medium			Yes	Do.
268	do.	do.	NW $\frac{1}{2}$ SE $\frac{1}{2}$ sec. 25, T. 17 N.	S. McAllister		Small			No	Stock.
269	do.	do.	R. 9 E.	do.	62	do.			Yes	Do.
270	do.	do.	NW $\frac{1}{2}$ sec. 10, T. 17 N., R. 9 E.	H. P. Schumacher	49	Medium			Yes	Domestic and stock.
271	do.	do.	SE $\frac{1}{2}$ sec. 27, T. 17 N., R. 9 E.	S. McAllister	47	do.			Yes	Do.
			NE $\frac{1}{2}$ sec. 35, T. 17 N., R. 9 E.	G. Okerman		do.			Yes	Domestic and stock.

272	do.	SE $\frac{1}{2}$ sec. 20, T. 17 N., R. 9 E.	S. McAllister	47	do.	Do.
273	do.	SE $\frac{1}{2}$ sec. 20, T. 17 N., R. 9 E.	do.	47	Medium	Do.
274	do.	NE $\frac{1}{2}$ sec. 19, T. 17 N., R. 9 E.	G. L. Lee		do.	Do.
275	do.	SW $\frac{1}{2}$ sec. 8, T. 17 N., R. 10 E.	J. B. Long		do.	Domestic, stock, and irrigation.
276	do.	SE $\frac{1}{2}$ sec. 19, T. 17 N., R. 10 E.	P. O'Hara	45	do.	Do.
277	do.	NW $\frac{1}{2}$ sec. 20, T. 17 N., R. 10 E.	J. H. Skelton	41	do.	Domestic.
278	do.	SE $\frac{1}{2}$ sec. 17, T. 17 N., R. 10 E.	J. Koto	49	Small	Yes
279	do.	SE $\frac{1}{2}$ sec. 20, T. 17 N., R. 10 E.	P. O'Hara	43	Medium	4,200
280	do.	NW $\frac{1}{2}$ sec. 19, T. 17 N., R. 10 E.	L. Waldeau	46	do.	4,300
281	do.	SE $\frac{1}{2}$ sec. 19, T. 17 N., R. 9 E.	Ann Downey		do.	Yes
282	do.	NE $\frac{1}{2}$ sec. 9, T. 16 N., R. 9 E.	Peter Van		Small	Yes
283	do.	NE $\frac{1}{2}$ sec. 17, T. 16 N., R. 9 E.	L. Bergeron	44	Large	Yes
284	do.	NW $\frac{1}{2}$ sec. 17, T. 16 N., R. 9 E.	D. Neud		do.	Yes
285	do.	SW $\frac{1}{2}$ sec. 5, T. 16 N., R. 9 E.	Delphas LeBlanc		Limestone	Do.
286	do.	NE $\frac{1}{2}$ sec. 5, T. 16 N., R. 9 E.	do.	43	Small	
287	do.	NE $\frac{1}{2}$ sec. 14, T. 16 N., R. 9 E.	Peter Van		do.	Domestic and stock.
288	do.	SW $\frac{1}{2}$ sec. 8, T. 16 N., R. 9 E.	O. Swanson	45	Small	Yes
289	do.	SW $\frac{1}{2}$ sec. 9, T. 16 N., R. 9 E.	do.		do.	Do.
290	do.	NE $\frac{1}{2}$ sec. 2, T. 16 N., R. 9 E.	J. M. Walters		do.	Do.
291	do.	Sec. 4, T. 16 N., R. 10 E.	T. Shannon	52	do.	Irrigation and stock.
292	do.	SE $\frac{1}{2}$ NE $\frac{1}{2}$ sec. 4, T. 16 N., R. 10 E.	do.	46	Medium	Irrigation.
293	do.	SW $\frac{1}{2}$ NW $\frac{1}{2}$ sec. 4, T. 16 N., R. 10 E.	do.	49	do.	Do.
294	do.	SW $\frac{1}{2}$ sec. 19, T. 16 N., R. 10 E.	P. O'Hara		Medium	Do.
295	do.	SW $\frac{1}{2}$ sec. 4, T. 16 N., R. 10 E.	J. H. Skelton	45	do.	Do.
296	do.	SW $\frac{1}{2}$ sec. 34, T. 16 N., R. 10 E.	H. G. Burgess	46	Drift	Do.
297	do.	SW $\frac{1}{2}$ sec. 20, T. 16 N., R. 10 E.	J. H. Skelton	42	Medium	Domestic and stock.
298	do.	SW $\frac{1}{2}$ sec. 25, T. 17 N., R. 10 E.	Thos. Higgins	51	do.	Yes
299	do.	do.	do.		Small	Yes
300	do.	do.	do.		do.	Do.
301	Fergus	Sec. 11, T. 17 N., R. 11 E.	Bower Bros.		do.	Domestic
302	do.	SE $\frac{1}{2}$ NE $\frac{1}{2}$ sec. 33, T. 17 N., R. 11 E.	do.		do.	Yes
303	Cascade	Secs. 1 and 2, T. 16 N., R. 10 E.	D. Butterfield		Small	No.
304	do.	do.	do.	48	Medium	Yes
305	do.	do.	do.	45	do.	Yes
306	do.	NE $\frac{1}{2}$ sec. 13, T. 16 N., R. 10 E.	do.	44	do.	Do.
307	do.	NW $\frac{1}{2}$ sec. 25, T. 16 N., R. 10 E.	Pool Ranch	46	Small	Do.
308	do.	NE $\frac{1}{2}$ sec. 25, T. 16 N., R. 10 E.	A. V. Cheney	52	Medium	Yes
309	do.	R. 10 E.	First National Bank	50	Small	Stock.
310	do.	SW $\frac{1}{2}$ sec. 34, T. 16 N., R. 10 E.	— Burgess	47	Medium	Domestic and stock.
311	do.	NW $\frac{1}{2}$ NW $\frac{1}{2}$ sec. 13, T. 16 N., R. 10 E.	First National Bank		do.	Stock (?)
312	Fergus	Sec. 25, T. 16 N., R. 10 E.	T. Higgins	51	do.	Stock.
313	do.	NE $\frac{1}{2}$ sec. 24, T. 16 N., R. 11 E.	Bower Bros.		do.	Do.
314	do.	SW $\frac{1}{2}$ sec. 13, T. 16 N., R. 11 E.	P. Westfall		Small	Yes
315	do.	NW $\frac{1}{2}$ sec. 13, T. 16 N., R. 11 E.	R. Skelton	48	Medium	Domestic and irrigation.
316	do.	do.	do.	48	do.	Do.

Partial list of springs of Great Falls region, Montana—Continued.

No.	County.	Locality.	Township, etc.	Owner.	Temperature.	Quantity.	Material from which spring issues.	Approximate elevation.	Is supply continuous?	Use.
316	Fergus	Stanford	SW. $\frac{1}{4}$ sec. 13, T. 16 N., R. 11 E.	E. F. Tuttle	° F.			Feet.		Irrigation.
317	do.	do.	SE. $\frac{1}{4}$ sec. 13, T. 16 N., R. 11 E.	do.	52	Medium			Yes	
318	do.	do.	SW. $\frac{1}{4}$ sec. 25, T. 16 N., R. 11 E.	G. H. Ketchner		Large			Yes	
319	do.	do.	Sec. 35, T. 16 N., R. 11 E.	Fisher Ranch	47	Medium				
320	do.	do.	NE. $\frac{1}{4}$ sec. 7, T. 16 N., R. 11 E.	Bower Bros.	55	Small	Sandstone			
321	do.	do.	NE. $\frac{1}{4}$ sec. 31, T. 16 N., R. 12 E.	S. S. Hobson	45	do.		4,900	Yes	Domestic and stock.
322	Cascade	do.	SE. $\frac{1}{4}$ sec. 2, T. 15 N., R. 10 E.	Butterfield						
323	Fergus	do.	Sec. 10, T. 15 N., R. 11 E.	Bower Bros.	47	Medium		2,000 (?)		Domestic, stock, and irrigation.
324	do.	do.	NE. $\frac{1}{4}$ sec. 3, T. 15 N., R. 11 E.	do.	46	Large			Yes	Domestic and stock.
325	do.	do.	SE. $\frac{1}{4}$ sec. 24, T. 15 N., R. 11 E.	J. Jehnick	46	Small			Yes	Stock.
326	do.	do.	SW. $\frac{1}{4}$ sec. 24, T. 15 N., R. 11 E.	do.		do.				Do.
327	do.	do.	SW. $\frac{1}{4}$ sec. 30, T. 15 N., R. 12 E.	Sage Creek Sheep Co.		Medium				Do.
328	do.	do.	SE. $\frac{1}{4}$ sec. 30, T. 15 N., R. 12 E.	do.		do.				Do.
329	do.	do.	SW. $\frac{1}{4}$ sec. 31, T. 15 N., R. 12 E.	do.		do.				Do.
330	do.	do.	SE. $\frac{1}{4}$ sec. 32, T. 15 N., R. 12 E.	do.		do.				Do.
331	do.	do.	NW. $\frac{1}{4}$ sec. 26, T. 15 N., R. 12 E.	do.		Small				Do.
332	do.	do.	NW. $\frac{1}{4}$ sec. 23, T. 15 N., R. 12 E.	do.		Medium				Do.
333	do.	do.	SW. $\frac{1}{4}$ sec. 4, T. 15 N., R. 12 E.	A. T. Kach	49	Medium	Sandstone			Do.

Partial list of wells of Great Falls region, Montana.

No.	County.	Locality.	Township, etc.	Owner.	Depth (feet).	Date completed.	Quality of water.	Is supply continuous?	How obtained at surface.	Geologic formation.	Use.
1	Teton	Chouteau	Sec. 30, T. 26 N., R. 5 W.	Nicolas Tuttle	130	1902		Yes			Domestic and stock.
2	do.	do.	Sec. 20, T. 26 N., R. 5 W.	do.	105	1902		Yes			Do.
3	do.	do.	SE. $\frac{1}{4}$ sec. 5, T. 25 N., R. 5 W.	Lewis A. Savik	40	1899	Slightly hard.	Yes			Do.
4	do.	do.	SE. $\frac{1}{4}$ sec. 28, T. 25 N., R. 4 W.	Bollerud Bros.	13	1898	Hard				Do.
5	do.	do.	SW. $\frac{1}{4}$ sec. 23, T. 25 N., R. 4 W.	Olaf Lindseth	13	1896	do.				Do.
6	do.	do.	SE. $\frac{1}{4}$ sec. 19, T. 25 N., R. 4 W.	J. Johnson	9	1905	Slightly hard.	Yes		Gravel	Do.

7	do	do	NE. sec. 6, T. 24 N., R. 5 W.	Earl Yeager.	65	Hard.	Yes.	Shale.	Do.
8	do	do	SW. sec. 3, T. 24 N., R. 4 W.	Abren Broere.	40	do	No water	Shale.	Do.
9	do	do	NW. sec. 2, T. 24 N., R. 4 W.	W. N. Van Der Riet.	80	do	Yes	Shale.	Do.
10	do	do	SW. sec. 19, T. 24 N., R. 4 W.	C. E. Moore.	30	Very hard	Yes	Gravel.	Domestic.
11	do	do	SW. sec. 5, T. 24 N., R. 4 W.	W. W. Gamble.	12	Slightly hard.	Yes	Shale.	Domestic and stock.
12	do	do	NE. sec. 5, T. 24 N., R. 4 W.	— Carlson.	12	Hard.	1894	Shale and gravel.	Domestic and stock.
13	do	do	SW. sec. 24, T. 23 N., R. 4 W.	Chris Lindeeth.	47	do	do	Shale.	Domestic.
14	do	do	NW. sec. 13, T. 22 N., R. 4 W.	J. Thom.	9	Fair.	Yes	Shale.	Domestic.
15	do	do	NE. sec. 1, T. 20 N., R. 6 W.	Mrs. C. C. Woods.	24	Good.	Yes	Shale.	Irrigation.
16	do	do	NE. sec. 7, T. 20 N., R. 5 W.	J. S. Lytle.	8	Alkaline.	Yes	Shale.	Stock.
17	do	do	SE. sec. 9, T. 20 N., R. 5 W.	P. Bickel.	34	do	Yes	Shale.	Domestic and stock.
18	do	do	Sec. 1, T. 20 N., R. 5 W.	Mrs. Fullberg.	20	Good.	Yes	Shale.	Domestic and stock.
19	do	do	Sec. 7, T. 20 N., R. 4 W.	H. C. Rell.	15	Hard.	Yes	Shale.	Domestic and stock.
20	do	do	Sec. 8, T. 20 N., R. 4 W.	H. J. Riedling.	22	Alkaline.	Yes	Shale.	Domestic and stock.
21	do	do	Sec. 5, T. 20 N., R. 4 W.	S. Eder.	12	Good.	Yes	Shale.	Stock.
22	do	do	SE. sec. 29, T. 22 N., R. 3 W.	Cole Bros.	10	Good.	Yes	Shale.	Stock.
23	do	do	NE. sec. 32, T. 22 N., R. 3 W.	do	16	do	Yes	Shale.	Stock.
24	do	do	NE. sec. 31, T. 22 N., R. 3 W.	E. G. Kufus.	20	do	No.	Shale.	Stock.
25	do	do	SE. sec. 31, T. 22 N., R. 3 W.	J. C. Kufus.	23	do	Yes	Shale.	Stock.
26	do	do	SE. sec. 35, T. 22 N., R. 3 W.	F. C. Kruks.	40	do	Yes	Shale.	Stock.
27	do	do	SW. sec. 35, T. 22 N., R. 3 W.	do	35	do	Yes	Shale.	Stock.
28	do	do	NE. sec. 30, T. 22 N., R. 2 W.	Z. Zimmerman.	75	Hard.	Yes	Shale.	Stock.
29	do	do	NE. sec. 5, T. 21 N., R. 3 W.	— Flowerree.	15	do	Yes	Shale.	Stock.
30	do	do	SW. sec. 20, T. 21 N., R. 2 W.	Cascade Land Co.	100	do	No.	Shale.	Stock.
31	do	do	SE. sec. 23, T. 20 N., R. 3 W.	J. F. Johnson.	18	Alkaline.	Yes	Shale.	Stock.
32	do	do	SW. sec. 10, T. 20 N., R. 3 W.	P. B. Fox.	20	Fair.	Yes	Shale.	Stock.
33	do	do	NW. sec. 22, T. 20 N., R. 3 W.	T. Seaquist.	71	do	Yes	Shale.	Stock.
34	do	do	NW. sec. 23, T. 20 N., R. 3 W.	do	15	do	Yes	Shale.	Stock.
35	do	do	NW. sec. 21, T. 20 N., R. 3 W.	G. LaRue.	11	Good.	Yes	Shale.	Stock.
36	do	do	SE. sec. 4, T. 20 N., R. 3 W.	H. Olson.	17	do	Yes	Shale.	Stock.
37	do	do	NW. sec. 4, T. 20 N., R. 3 W.	— Flowerree.	65	do	Yes	Shale.	Stock.
38	do	do	NE. sec. 10, T. 20 N., R. 3 W.	D. B. Todd.	20	do	Yes	Shale.	Stock.
39	do	do	Sec. 33, T. 20 N., R. 2 W.	Sun River Land and Stock Co.	10	do	Yes	Shale.	Stock.
40	do	do	NE. sec. 31, T. 20 N., R. 2 W.	do	108	do	No.	Shale.	Stock.
41	do	do	Sec. 4, T. 24 N., R. 1 W.	do	108	do	Yes	Shale.	Stock.
42	do	do	Sec. 22, T. 23 N., R. 1 W.	do	110	do	Yes	Shale.	Stock.
43	do	do	do	do	110	do	Yes	Shale.	Stock.
44	do	do	SW. sec. 29, T. 22 N., R. 1 W.	Noble Bros.	85	Alkaline.	Yes	Shale.	Stock.
45	do	do	NE. sec. 31, T. 21 N., R. 1 W.	D. Davies.	20	do	Yes	Shale.	Stock.
46	do	do	SE. sec. 30, T. 21 N., R. 1 W.	Ford ranch.	15	do	Yes	Shale.	Stock.
47	do	do	SW. sec. 30, T. 21 N., R. 1 W.	M. L. Strong.	25	do	Yes	Shale.	Stock.
48	do	do	NE. sec. 34, T. 21 N., R. 1 W.	J. C. Adams.	63	Soft.	Yes	Shale.	Stock.
49	do	do	NW. sec. 36, T. 21 N., R. 1 W.	E. C. Blossom.	80	Hard.	Yes	Shale.	Stock.
50	do	do	NW. sec. 2, T. 20 N., R. 1 W.	Gouch Bros.	96	Alkaline.	Yes	Shale.	Stock.
51	do	do	NE. sec. 25, T. 21 N., R. 1 W.	B. Thomas.	15	do	Yes	Shale.	Stock.
52	do	do	NE. sec. 27, T. 21 N., R. 1 W.	— Hollart.	10	do	Yes	Shale.	Stock.
53	do	do	Sec. 12, T. 20 N., R. 1 E.	do	140	do	Yes	Shale.	Stock.
54	do	do	Sec. 14, T. 20 N., R. 1 E.	— Swager.	128	do	Yes	Shale.	Stock.
55	do	do	do	do	90	do	Yes	Shale.	Stock.

Partial list of wells of Great Falls region, Montana—Continued.

No.	County.	Locality.	Township, etc.	Owner.	Depth (feet).	Date com- pleted.	Quality of water.	Is supply continuous?	How ob- tained at surface.	Geologic formation.	Use.
56	Cascade	Sun River.	NE $\frac{1}{4}$ sec. 13, T. 19 N., R. 2 W.	Toman Bros.	40					Sandstone.	Stock.
57	do	do	NW $\frac{1}{4}$ sec. 12, T. 19 N., R. 1 W.	Ed. Bull.	35						Do.
58	do	do	NE $\frac{1}{4}$ sec. 22, T. 19 N., R. 1 W.	D. E. Rease.	30		Alkaline.				Domestic and stock.
59	do	do	NW $\frac{1}{4}$ sec. 21, T. 19 N., R. 1 W.	E. A. Weiland	10	1890	Hard	Yes			Domestic.
60	do	do	SE $\frac{1}{4}$ sec. 35, T. 18 N., R. 1 W.	H. F. Montag.	15						
61	do	do	Sec. 13, T. 18 N., R. 1 W.	W. Bochna	18						
62	do	do	do	do	30						
63	do	do	Sec. 26, T. 18 N., R. 1 W.	Cascade Water- works.	78		Hard				
64	do	do	Sec. 35, T. 18 N., R. 1 W.	do	25		do			Alluvium.	
65	do	do	do	H. Schrameck	18		do	Yes	Windmill		Domestic, stock, ir- rigation, and man- ufacturing.
66	do	do	SE $\frac{1}{4}$ sec. 37, T. 18 N., R. 1 W.	do	17	1882	do				Domestic, stock, and irrigation.
67	do	do	NW $\frac{1}{4}$ sec. 30, T. 18 N., R. 1 E.	Benj. Rumney	20	1890	do	Yes	Pump		Domestic, stock, and irrigation.
68	do	do	NW $\frac{1}{4}$ sec. 1, T. 18 N., R. 1 E.	James Travis	12	1889	Iron	Yes	do		Domestic.
69	do	do	Sec. 24, T. 18 N., R. 1 E.	Sam Jones	30		Soft	Yes	Pump		Domestic.
70	do	do	Sec. 8, T. 17 N., R. 1 E.	Sam Kelly	30	1886	do	Yes	do		Domestic.
71	do	do	SE $\frac{1}{4}$ sec. 8, T. 17 N., R. 1 E.	G. H. Crum	65	1886	Hard	No	do		Domestic.
72	do	do	T. 17 N., R. 1 E.	Aug. Wedsworth	16	1885	do	Yes	do		Domestic.
73	do	do	Sec. 20, T. 19 W., R. 2 E.	J. Ferguson	278			No water			
74	do	do	Sec. 29, T. 19 N., R. 2 E.	T. C. King	80			Yes			
75	do	do	Sec. 28, T. 19 N., R. 2 E.	G. S. Ferguson	30			Yes			
76	do	do	Sec. 26, T. 19 N., R. 2 E.	Sanden T. Hops	50			Yes			
77	do	do	Sec. 31, T. 19 N., R. 3 E.	Pridle	68		Soft	No	Windmill		Do.
78	do	do	Sec. 29, T. 19 N., R. 3 E.	A. Hickey	72		Good	No			Domestic, stock, and irrigation.
79	do	Truly	Sec. 21, T. 18 N., R. 2 E.	McLaughlin	10		Hard				
80	do	do	do	Cummins	65		do				
81	do	do	SW $\frac{1}{4}$ sec. 16, T. 18 N., R. 2 E.	— Cranston.	8		Alkaline	No			
82	do	do	Sec. 21, T. 18 N., R. 2 E.	Perry	8		do				
83	do	do	Sec. 17, T. 18 N., R. 2 E.	J. A. Perrine	17		Hard				
84	do	do	do	do	22		do				
85	do	do	do	do	125		do				
86	do	do	Sec. 18, T. 18 N., R. 2 E.	J. W. Perrine	49	1902	do		Bucket		
87	do	do	Sec. 17, T. 18 N., R. 2 E.	W. G. Stone	33	1905	do	Yes			Domestic and stock.
88	do	do	Sec. 7, T. 18 N., R. 2 E.	J. S. Ferguson	25			Yes			Stock.
89	do	do	Sec. 8, T. 18 N., R. 2 E.	R. Richardson	12	1905	Hard	Yes			Domestic and stock.
90	do	do	Sec. 2, T. 18 N., R. 2 E.	do	17						
91	do	do	do	Hughes	16			No			
92	do	do	NE $\frac{1}{4}$ sec. 28, T. 18 N., R. 2 E.	J. H. Daly	225		No water	No			
93	do	do	do	do	75		Soft	Yes			

[illegible]

Partial list of wells of Great Falls region, Montana—Continued.

No.	County.	Locality.	Township, etc.	Owner.	Depth (feet).	Date completed.	Quality of water.	Is supply continuous?	How obtained at surface.	Geologic formation.	Use.
139	Cascade	Great Falls...	SE. 1 sec. 29, T. 20 N., R. 2 E.	A. W. Craig	32		Alkaline				
140	do.	do.	NE. 1 sec. 28, T. 20 N., R. 2 E.	do.	15						
141	do.	do.	SE. 1 sec. 29, T. 20 N., R. 2 E.	do.	6		Alkaline				
142	do.	do.	do.	do.	6		Alkaline				
143	do.	do.	do.	do.	15		do.				
144	do.	do.	do.	do.	45			Yes			
145	do.	do.	NE. 1 sec. 34, T. 20 N., R. 2 E.	do.	10			No water			
146	do.	do.	NW. 1 sec. 33, T. 20 N., R. 2 E.	do.	525			Yes			
147	do.	do.	do.	do.	90			No water			
148	do.	do.	NE. 1 sec. 23, T. 20 N., R. 2 E.	do.	125						
149	do.	do.	SE. 1 sec. 35, T. 20 N., R. 2 E.	do.	8						
150	do.	do.	SW. 1 sec. 25, T. 20 N., R. 2 E.	do.	94		Alkaline	Yes			
151	do.	do.	SE. 1 sec. 15, T. 20 N., R. 2 E.	C. K. Giles	57		Good.	Yes			
152	do.	do.	NE. 1 sec. 15, T. 20 N., R. 2 E.	Shobert	12						
153	do.	do.	Sec. 19, T. 20 N., R. 2 E.	Cherpecki	91						
154	do.	do.	Sec. 20, T. 20 N., R. 2 E.	Stewart	76						
155	do.	do.	Sec. 21, T. 20 N., R. 2 E.	Weber	71		Good.				
156	do.	do.	SW. 1 sec. 23, T. 20 N., R. 2 E.	Arnold	133						
157	do.	do.	Sec. 15, T. 20 N., R. 2 E.	Rumbeaugh	76		Good.				
158	do.	do.	Sec. 13, T. 20 N., R. 2 E.	Geerson	51						
159	do.	do.	Sec. 9, T. 20 N., R. 2 E.	Carruthers	123						
160	do.	do.	Sec. 22, T. 20 N., R. 2 E.	Boynton	320						
161	do.	do.	SW. 1 sec. 17, T. 20 N., R. 3 E.	Peter Dindolad	114	1906	Good.	Yes		Shale.	Do.
162	do.	do.	SE. 1 sec. 30, T. 20 N., R. 3 E.	G. D. Nicolai	61	1904	Hard.	Yes			Do.
163	do.	do.	Sec. 21, T. 20 N., R. 4 E.	P. Gibson	25						
164	do.	do.	NW. 1 sec. 22, T. 20 N., R. 4 E.	do.	17						
165	do.	do.	SE. 1 sec. 20, T. 20 N., R. 4 E.	do.	14						
166	do.	do.	SW. 1 sec. 27, T. 20 N., R. 4 E.	do.	18						
167	do.	do.	NE. 1 sec. 32, T. 20 N., R. 4 E.	do.	27		Hard.				
168	do.	do.	do.	John Locke	56	1906	do.				Do.
169	do.	do.	do.	W. H. Mitchell	9	1906	do.				Do.
170	do.	do.	NW. 1 sec. 31, T. 20 N., R. 4 E.	W. F. Jenkin	126	1904	do.	Yes	Windmill.	Gravel and clay.	Stock.
			NE. 1 sec. 26, T. 20 N., R. 4 E.	Great Falls Meat Co.							
171	do.	do.	SW. 1 sec. 13, T. 20 N., R. 4 E.	do.	300	1895	Very poor				
172	do.	do.	NE. 1 sec. 4, T. 20 N., R. 4 E.	do.	300	1893	Poor.				
173	do.	do.	NW. 1 sec. 15, T. 20 N., R. 4 E.	do.	165	1893					
174	do.	do.	SE. 1 sec. 25, T. 20 N., R. 4 E.	F. Yost	23		Hard.		Windmill.	Alluvium.	Do.
175	do.	do.	SE. 1 sec. 20, T. 20 N., R. 4 E.	do.	4		Good.	Yes	do.		
176	do.	do.	NE. 1 sec. 26, T. 20 N., R. 4 E.	Lee ranch							
177	do.	do.	SW. 1 sec. 8, T. 20 N., R. 5 E.	do.							
178	do.	do.	SW. 1 sec. 2, T. 20 N., R. 5 E.	Great Falls Meat Co	300	1904	Soft.	Yes		Alluvium.	
179	do.	do.	SE. 1 sec. 32, T. 20 N., R. 5 E.	E. Grieger	10						
180	do.	do.	SW. 1 sec. 31, T. 20 N., R. 5 E.	do.	5		Soft.				

181	do.	do.	NE. $\frac{1}{2}$ sec. 18, T. 19 N., R. 4 E.	A. Mobray.	45	1903	Hard.			Domestic and stock. Do.
182	do.	do.	do.	do.	160	1905	do.			Domestic.
183	do.	do.	SE. $\frac{1}{2}$ sec. 18, T. 19 N., R. 4 E.	John R. Ross.	45	1897	do.			Domestic and stock.
184	do.	do.	SW. $\frac{1}{2}$ sec. 30, T. 19 N., R. 4 E.	R. Skinner.	85	do.	do.			Domestic.
185	do.	do.	NE. $\frac{1}{2}$ sec. 12, T. 19 N., R. 4 E.	J. G. Ernst.	32	do.	do.	No.	Pump	Domestic and stock.
186	do.	do.	NE. $\frac{1}{2}$ sec. 12, T. 19 N., R. 5 E.	Ray & Freidrich Sheep Co.	175	do.	Very hard	Yes.		
187	do.	do.	NE. $\frac{1}{2}$ sec. 9, T. 19 N., R. 5 E.	A. Farling.	12		Good	Yes.	Pump	
188	do.	do.	SW. $\frac{1}{2}$ sec. 9, T. 19 N., R. 5 E.	J. Dougherty.	12		do.	No.		
189	do.	do.	do.	do.	30		do.	No.		
190	do.	do.	SE. $\frac{1}{2}$ sec. 27, T. 19 N., R. 4 E.	J. Eisenberg.	32		Hard	No.		
191	do.	do.	NE. $\frac{1}{2}$ sec. 27, T. 19 N., R. 4 E.	Edmund Dirk.	110		Very hard	No.		
192	do.	do.	SW. $\frac{1}{2}$ sec. 33, T. 19 N., R. 4 E.	John Edstrom.	30		Good	No.		
193	do.	do.	SW. $\frac{1}{2}$ sec. 33, T. 19 N., R. 4 E.	C. W. Peterson.	40		Hard	No.		
194	do.	do.	Sec. 36, T. 19 N., R. 4 E.	Cottonwood Coal Co.	50	1904	do.	No.		
195	do.	do.	Sec. 23, T. 19 N., R. 5 E.	W. E. Aernathy.	15		Soft	Yes.		
196	do.	do.	do.	do.	30		Hard			
197	do.	do.	SW. $\frac{1}{2}$ sec. 35, T. 18 N., R. 4 E.	J. G. Martin.	19		do.			
198	do.	do.	Sec. 21, T. 18 N., R. 4 E.	J. H. Connor.	22		do.			
199	do.	do.	Sec. 33, T. 18 N., R. 4 E.	J. P. Jones.	30	1902	Hard	Yes.		
200	do.	do.	NE. $\frac{1}{2}$ sec. 17, T. 18 N., R. 4 E.	C. Jaekel.	14	1889	do.	do.		
201	do.	do.	NE. $\frac{1}{2}$ sec. 31, T. 18 N., R. 4 E.	John Steyaert.	30	1905	do.	do.		
202	do.	do.	NE. $\frac{1}{2}$ sec. 34, T. 18 N., R. 4 E.	N. J. Wagner.	280	1902	do.	do.		
203	do.	do.	do.	do.	45		Hard			
204	do.	do.	SW. $\frac{1}{2}$ sec. 35, T. 18 N., R. 4 E.	Wm. Kirby.	180		do.	Yes	Windmill.	
205	do.	do.	SE. $\frac{1}{2}$ sec. 25, T. 18 N., R. 4 E.	Chester Cavanagh.	20	1898	Soft	Yes		
206	do.	do.	Sec. 19, T. 18 N., R. 5 E.	A. Winkle.	115	1902	Hard	No.		
207	do.	do.	SE. $\frac{1}{2}$ sec. 31, T. 18 N., R. 5 E.	Chas. Gereke.	205		do.	Yes		
208	do.	do.	do.	J. Mettish.	120	1903	Hard	do.		
209	do.	do.	do.	do.	200		do.	No.		
210	do.	do.	Sec. 12, T. 18 N., R. 5 E.	John Ross.	150	1902	Hard	No.		
211	do.	do.	Sec. 14, T. 18 N., R. 5 E.	A. Carlson.	65		do.	Yes	Windmill.	
212	do.	do.	do.	do.	20		Soft	No.		
213	do.	do.	SW. $\frac{1}{2}$ sec. 14, T. 18 N., R. 5 E.	Penn Bros.	35		Soft	No.		
214	do.	do.	Sec. 24, T. 18 N., R. 5 E.	do.	11		do.	Yes		
215	do.	do.	NE. $\frac{1}{2}$ sec. 26, T. 18 N., R. 5 E.	J. M. Mahoney.	26		Slightly hard.	Yes		
216	do.	do.	Sec. 18, T. 18 N., R. 5 E.	J. Knabe.	65		Soft	No.		
217	do.	do.	do.	B. Goethe.	15		do.	Yes		
218	do.	do.	Sec. 21, T. 18 N., R. 5 E.	Young & Jeffries.	9		do.	No.		
219	do.	do.	Sec. 1, T. 18 N., R. 5 E.	O. Romundstad.	40	1905	Soft	do.		
220	do.	do.	Sec. 12, T. 18 N., R. 5 E.	W. Shoop.	200		do.	No.	Windmill.	
221	do.	do.	Sec. 11, T. 17 N., R. 4 E.	Wellington Gates.	50	1905	Soft	do.		
222	do.	do.	NE. $\frac{1}{2}$ sec. 2, T. 17 N., R. 4 E.	L. E. Betts.	120	1905	Hard	do.		
223	do.	do.	Sec. 26, T. 20 N., R. 6 E.	J. B. Long.	20		do.	do.	Windmill.	
224	do.	do.	NE. $\frac{1}{2}$ sec. 32, T. 20 N., R. 6 E.	Mack Depew.	25		do.	do.		
225	do.	do.	SE. $\frac{1}{2}$ sec. 25, T. 20 N., R. 6 E.	J. A. Demuth.	50	1906	Poor.	do.		
226	do.	do.	do.	do.	25		do.	do.	Blue lime-stone.	
227	do.	do.	NE. $\frac{1}{2}$ sec. 24, T. 20 N., R. 6 E.	J. B. Metzell.	25		do.	do.	Steam engine. Pump	
228	do.	do.	SE. $\frac{1}{2}$ sec. 13, T. 20 N., R. 6 E.	J. B. Young.	12		do.	No.		
229	do.	do.	NE. $\frac{1}{2}$ sec. 31, T. 20 N., R. 6 E.	L. F. Leech.	14		Poor.	No.		

Partial list of wells of Great Falls region, Montana—Continued.

No.	County.	Locality.	Township, etc.	Owner.	Depth (feet).	Date com- pleted.	Quality of water.	Is supply continu- ous?	How ob- tained at surface.	Geologic formation.	Use.
230	Cascade	Stockett.	NW 1 sec. 32, T. 20 N., R. 6 E.	J. Dougherty.	15						Stock Do.
231	do	do	Sec. 32, T. 20 N., R. 6 E.	do.	20		Soft.				
232	do	do	NW 1 sec. 29, T. 20 N., R. 6 E.	do.	20		Hard				
233	do	do	NE 1 sec. 18, T. 20 N., R. 7 E.	J. Epperson.	14	1886	Good	Yes	Pump		Domestic and stock. Do.
234	do	do	Sec. 33, T. 20 N., R. 7 E.	Chillette.	14	1905	do	Yes	do		Domestic.
235	do	do	NE 1 sec. 15, T. 19 N., R. 6 E.	A. H. McMillan.	80		do	Yes	Bucket		
236	do	do	SE 1 sec. 22, T. 19 N., R. 6 E.	Rush Farm.	8		Hard	Yes			
237	do	do	Sec. 10, T. 19 N., R. 6 E.	Kuperion.	20		Good	Yes			
238	do	do	Sec. 5, T. 19 N., R. 6 E.	W. H. Porter.	8		do	Yes			
239	do	do	Sec. 21, T. 19 N., R. 6 E.	Henry Kassmer.	35		do	No			Domestic and stock.
240	do	do	Sec. 14, T. 19 N., R. 6 E.	C. B. Pyle.	35		do	No			Do.
241	do	do	do	F. Polutnik.	64			No	Bucket		
242	do	do	do	do.	80			Yes	Windmill		
243	do	do	do	John Wright.	10	1900					
244	do	do	do	do.	40			Yes			
245	do	do	Sec. 1, T. 19 N., R. 6 E.	W. S. Sifford.	25		Poor.	No			
246	do	do	Sec. 11, T. 19 N., R. 6 E.	Geo. Togden.	27		do	No			
247	do	do	do	do.	175		Good	Yes			
248	do	do	NW 1 sec. 3, T. 19 N., R. 6 E.	Jno and Joe Bogner.	25			Yes	Pump		Domestic stock, and irrigation.
249	do	do	Sec. 16, T. 19 N., R. 6 E.	Edgar Mann.	14	1905	Hard				
250	do	do	do	do.	20	1900	Soft.	Yes	do		
251	do	do	NE 1 sec. 32, T. 19 N., R. 6 E.	C. Turner.	120	1887		No wa- ter.			
252	do	do	Sec. 15, T. 19 N., R. 6 E.	A. H. McMillan.	80		Soft.	Yes	Pump		Domestic and stock.
253	do	do	NW 1 sec. 6, T. 19 N., R. 6 E.	S. Dean.	14	1905	Slightly hard.	Yes		Alluvium.	
254	do	do	Sec. 34, T. 19 N., R. 6 E.	Cottonwood Coal Co.	100						
255	do	do	Sec. 21, T. 19 N., R. 6 E.	Chas. Lindsey.	35	1902	Slightly hard.	Fairly	Pump		Do.
256	do	do	SE 1 sec. 2, T. 19 N., R. 7 E.	J. F. McCraw.	20					Alluvium.	
257	do	do	NE 1 sec. 33, T. 19 N., R. 6 E.	O. V. Jacobs.	8						
258	do	do	NE 1 sec. 28, T. 18 N., R. 6 E.	Hans Johnson.	4				G a soline engine.		
259	do	do	SE 1 sec. 20, T. 18 N., R. 6 E.	J. Nelson.	217						
260	do	do	SE 1 sec. 25, T. 18 N., R. 6 E.	N. Neumeyer.	10						Do.
261	do	do	Sec. 36, T. 18 N., R. 6 E.	G. Stelling.	22		Soft.				
262	do	do	NE 1 sec. 15, T. 18 N., R. 6 E.	J. R. Green.	23		Hard				Stock Domestic and stock.
263	do	do	NE 1 sec. 1, T. 18 N., R. 6 E.	D. G. Galt.	40		Good	Yes	Windmill	Sandstone Shale.	
264	do	do	SW 1 sec. 14, T. 18 N., R. 6 E.	F. Polutnik.	30	1904					
265	do	do	Sec. 7, T. 18 N., R. 7 E.	S. D. Winston.	35						
266	do	do	NE 1 sec. 5, T. 18 N., R. 7 E.	J. T. Bough.	17		Good	No			

237	do.	do.	Sec. 11, T. 18 N., R. 7 E.	F. Armstrong.	13	No.				Domestic.
238	do.	do.	Sec. 11, T. 18 N., R. 7 E.	W. R. Cresop.	22	Yes.				Domestic, stock, and garden.
239	do.	do.	Sec. 29, T. 18 N., R. 8 E.	F. J. Ober.	16					Stock.
240	do.	do.	Sec. 20, T. 18 N., R. 8 E.	J. W. Watkins.	20	1904	Good	Pump	Sandstone	Domestic.
241	do.	do.	Sec. 28, T. 18 N., R. 8 E.	Rob. Williamson.	14		Alkaline	Bucket	Alluvium	
242	do.	do.	SW $\frac{1}{4}$ sec. 1, T. 17 N., R. 6 E.	G. W. Albright.	10					
243	do.	do.	SW $\frac{1}{4}$ sec. 10, T. 18 N., R. 8 E.	W. McGinnis.	21					
244	do.	do.	NE $\frac{1}{4}$ sec. 13, T. 18 N., R. 8 E.	J. Camerton.	40	1900				
245	do.	do.	NE $\frac{1}{4}$ sec. 24, T. 18 N., R. 8 E.	H. Koskey.	7		Soft		Shale	
246	do.	do.	NE $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 14, T. 18 N., R. 9 E.	W. Kernaghan.	23		do.		Clay	
247	do.	do.	SW $\frac{1}{4}$ SW $\frac{1}{4}$ sec. 12, T. 18 N., R. 9 E.	J. Todd.	9		do.			
248	do.	do.	NW $\frac{1}{4}$ sec. 14, T. 18 N., R. 9 E.	R. O'Connor.	15		do.			
249	do.	do.	S $\frac{1}{4}$ sec. 2, T. 18 N., R. 9 E.	F. McClint.	15		Soft	Pump		Domestic and garden.
250	do.	do.	SW $\frac{1}{4}$ sec. 20, T. 18 N., R. 9 E.	D. Rankin.	14	1900				Domestic.
251	do.	do.	NE $\frac{1}{4}$ sec. 35, T. 18 N., R. 9 E.	Gabriel Takola.	5	1905	do.	Bucket		Do.
252	do.	do.	NW $\frac{1}{4}$ sec. 32, T. 18 N., R. 10 E.	J. B. Long.	15			Pump		Do.
253	do.	do.	SE $\frac{1}{4}$ sec. 32, T. 18 N., R. 10 E.	do.	15			do.		Do.
254	do.	do.	NE $\frac{1}{4}$ sec. 3, T. 17 N., R. 8 E.	— Larson.	15	1881	Soft	do.		Domestic, stock, and garden.
255	do.	do.	NE $\frac{1}{4}$ sec. 2, T. 17 N., R. 9 E.	H. Hanula.	8		do.			Domestic and stock.
256	do.	do.	NW $\frac{1}{4}$ sec. 28, T. 17 N., R. 9 E.	W. Nollar.	25					Domestic.
257	do.	do.	SW $\frac{1}{4}$ sec. 10, T. 17 N., R. 9 E.	H. P. Schumacher.	23		Hard		Limestone	
258	do.	do.	SE $\frac{1}{4}$ sec. 5, T. 16 N., R. 9 E.	Delphas Leblanc.	14		Poor	Bucket		Stock.
259	do.	do.	SW $\frac{1}{4}$ sec. 26, T. 16 N., R. 9 E.	— Peterson.	8					Domestic and stock.
260	do.	do.	SW $\frac{1}{4}$ sec. 19, T. 16 N., R. 10 E.	P. O'Hara.	8					Do.
261	do.	do.	SE $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 33, T. 17 N., R. 11 E.	Bower Bros.	30	1880				Stock.
262	do.	do.	NW $\frac{1}{4}$ sec. 27, T. 17 N., R. 12 E.	do.	15			Pump		Do.
263	do.	do.	NW $\frac{1}{4}$ sec. 22, T. 17 N., R. 12 E.	do.	20		Soft	do.		Do.
264	do.	do.	SW $\frac{1}{4}$ NW $\frac{1}{4}$ sec. 11, T. 17 N., R. 12 E.	T. Bain.	20					Do.
265	do.	do.	R. 12 E.	Bower Bros.				Pump		Do.
266	do.	do.	Sec. 27, T. 17 N., R. 12 E.	do.						Do.
267	do.	do.	SW $\frac{1}{4}$ NW $\frac{1}{4}$ sec. 27, T. 17 N., R. 12 E.	do.						Do.
268	do.	do.	R. 12 E.	do.						Do.
269	do.	do.	NW $\frac{1}{4}$ sec. 11, T. 17 N., R. 12 E.	do.	15			Windmill		Do.
270	do.	do.	NE $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 3, T. 17 N., R. 12 E.	do.	15					Do.
271	do.	do.	R. 12 E.	do.						Do.
272	do.	do.	SW $\frac{1}{4}$ SW $\frac{1}{4}$ sec. 13, T. 16 N., R. 11 E.	P. Westfall.	12		Hard		Drift	
273	do.	do.	NW $\frac{1}{4}$ NW $\frac{1}{4}$ sec. 13, T. 16 N., R. 11 E.	J. Skelton.	10		Soft			
274	do.	do.	NE $\frac{1}{4}$ sec. 13, T. 16 N., R. 11 E.	E. F. Tuttle.	12		Hard			
275	do.	do.	Sec. 24, T. 16 N., R. 11 E.	W. Skelton.	15		do.			
276	do.	do.	SW $\frac{1}{4}$ sec. 25, T. 16 N., R. 11 E.	G. H. Ketchner.	18		do.			
277	do.	do.	Sec. 35, T. 16 N., R. 11 E.	Fisher ranch.	12		Soft			
278	do.	do.	NE $\frac{1}{4}$ sec. 24, T. 16 N., R. 11 E.	W. Skelton.	15	1900		Pump		Do.
279	do.	do.	Sec. 31, T. 16 N., R. 12 E.	S. S. Hobson.	12		Hard			

Partial list of wells of Great Falls region, Montana—Continued.

No.	County.	Locality.	Township, etc.	Owner.	Depth. (feet).	Date com- pleted.	Quality of water.	Is supply contin- uous?	How ob- tained at surface.	Geologic formation.	Use.
309	Fergus	Stanford	NW $\frac{1}{4}$ NW $\frac{1}{4}$ sec. 23, T. 15 N., R. 12 E.	Sage Sheep Creek Co.				Yes			Irrigation.
310	do.	do.	NE $\frac{1}{4}$ NW $\frac{1}{4}$ sec. 4, T. 15 N., R. 12 E.	J. Begla.	9		Good	Yes		Sandstone.	
311	do.	do.	Sec. 4, T. 15 N., R. 12 E.	do.	20		do.	Yes		do.	
312	do.	do.	do.	A. T. Koch.	25		do.	Yes		Shale.	
313	do.	do.	SE $\frac{1}{4}$ SW $\frac{1}{4}$ sec. 18, T. 15 N., R. 12 E.	W. J. Hughes.	18		do.	Yes		Sandstone.	

Artesian wells in the Great Falls region, Montana.

No.	County.	Locality.	Township, etc.	Owner.	Depth.	Diameter.	Date drilled.	Estimated flow per minute.	Quality of water.	Use.	Remarks.
1	Teton	Farmington	SW $\frac{1}{4}$ sec. 35, T. 26 N., R. 4 W.	Francois Truchot	47	1 $\frac{1}{2}$	1904	1	Good	Not used	
2	do.	do.	SW $\frac{1}{4}$ sec. 2, T. 25 N., R. 4 W.	do.	50	2	1900	1	do	Stock	
3	do.	do.	NE $\frac{1}{4}$ sec. 11, T. 25 N., R. 4 W.	do.	50	2	1900	1	do	do.	
4	do.	do.	SE $\frac{1}{4}$ sec. 23, T. 26 N., R. 4 W.	do.	100	2		1	do	do.	
5	do.	do.	NW $\frac{1}{4}$ sec. 35, T. 26 N., R. 4 W.	H. Weiske	45	2			do	Domestic and stock	Barely rises above surface.
6	do.	do.	NW $\frac{1}{4}$ sec. 2, T. 25 N., R. 4 W.	G. A. Gorum	45	2	1903	1	do	Stock	
7	do.	do.	SE $\frac{1}{4}$ sec. 21, T. 26 N., R. 4 W.	B. P. Dirksen	45	2	1902	1	do	do.	
8	do.	do.	SE $\frac{1}{4}$ sec. 15, T. 26 N., R. 4 W.	J. P. Schmidt	75	2		1	do	do.	
9	do.	do.	SE $\frac{1}{4}$ sec. 11, T. 25 N., R. 4 W.	John Jackson	37 $\frac{1}{2}$	2	1903	1	do	Domestic and stock	
10	do.	do.	do.	do.	34 $\frac{1}{2}$	2	1905	1	do	Irrigation	
11	do.	do.	SW $\frac{1}{4}$ sec. 11, T. 25 N., R. 4 W.	do.	28	3 $\frac{1}{2}$	1906	1	do	do.	
12	do.	do.	do.	do.	35	3	1906	1	do	do.	
13	do.	do.	NE $\frac{1}{4}$ NW $\frac{1}{4}$ sec. 6, T. 25 N., R. 4 W.	Peter Egraud	87	5 $\frac{1}{2}$	1899	2	do	Domestic stock, ir- rigation.	Closed.
14	do.	do.	Sec. 6, T. 25 N., R. 4 W.	do.	87	5			do	Domestic stock, ir- rigation.	
15	do.	do.	do.	do.	91	8		1	do	do.	

No.	Locality	Section	Depth	Strata	Remarks	Notes	Do.
16	do.	do.	do.	do.	do.	83	
17	do.	do.	do.	do.	do.	31	Irrigation.
18	do.	do.	do.	do.	do.	31	do.
19	do.	do.	do.	do.	do.	31	do.
20	do.	do.	do.	do.	do.	6	do.
21	do.	do.	do.	do.	do.	2	do.
22	do.	do.	do.	do.	do.	16	do.
23	do.	do.	do.	do.	do.	2	do.
24	do.	do.	do.	do.	do.	2	do.
25	do.	do.	do.	do.	do.	2	do.
26	Fergus.	Stanford.	do.	do.	do.	36	do.
27	do.	do.	do.	do.	do.	321	do.
28	do.	do.	do.	do.	do.	850	do.
29	do.	do.	do.	do.	do.	400	do.
30	do.	do.	do.	do.	do.	400	do.
31	do.	do.	do.	do.	do.	700	do.
32	do.	do.	do.	do.	do.	900	do.
33	Cascade.	Belt.	do.	do.	do.	95	do.
34	do.	Great Falls.	do.	do.	do.	160	do.
35	do.	do.	do.	do.	do.	180	do.

300 barrels in 24 hours.

ARTESIAN CONDITIONS.

Throughout the eastern part of the area examined, especially that lying east of Belt Creek, the geologic conditions are in general favorable for the occurrence of artesian water. The rocks consist of medium to coarse grained massive sandstone and sandy shale overlain by impervious shale and clay. They dip gradually to the northeast away from the mountains, so that the streams passing over the upturned ends of this porous sandstone and shale lose much of their water. This water in passing underground is soon carried beneath impervious shale farther down on the plains, where it is available as artesian water when the overlying shale is penetrated by deep-well borings. These conditions obtain throughout a zone of varying width along Sage, Willow, Skull, Running Wolf, Surprise, and Arrow Creek valleys.

Throughout the area lying between Belt Creek and Smith River the general geologic and structural conditions are not favorable for the occurrence of artesian water. There is, however, a shallow flowing well of local origin in Box Elder Creek which probably derives its water from the valley filling. In this general vicinity the sandstone members of the Kootenai and the base of the Colorado formation, which are the principal artesian water-bearing beds to the east, occupy summits of more or less detached plateaus, which rise to the south toward the highland lying between the Big Belt and Little Belt mountains. As these sandstone members, which in other localities are artesian water-bearing, occupy only the summits of the higher table-lands far above the mountain streams draining the area, the only water which they can receive is that derived from rainfall. A portion of this is disposed of by run-off and evaporation, while the remainder is free to escape in the numerous marginal springs which occur along the edge of the above-described plateaus; hence the region is one where artesian water is not to be expected.

From Smith River westward along the base of the adjacent mountain ranges the geologic and structural conditions, although different from those above described, are equally unfavorable for the occurrence of artesian water in the adjoining plains region. Along the northern base of Big Belt Mountains the sedimentary rocks, which are of upper Cretaceous age, are cut by igneous rocks over extensive areas, thus preventing them from extending into the higher mountain regions where they might be free to absorb water. The same is true along the base of the Lewis Range bordering this area on the west. Cretaceous rocks, instead of dipping normally away from the uplift, owing to the overthrust fault above described dip toward the mountains, passing under the older Algonkian rocks, which form the higher portion of the range. In the region lying west of Great Falls the water-bearing sandstones of the Kootenai and the base of the

Colorado formation are not exposed, but are covered by several hundred feet of upper Cretaceous sediment, consisting mainly of impervious shale with sandstone members in the upper part. Under these conditions it is apparent that rocks which are water-bearing on the east are on the west, along the base of the Lewis Mountains, completely sealed off from a surface water supply by a great thickness of overlying impervious shale of upper Cretaceous age. The sandstone beds in the upper part of the upper Cretaceous formation also dip toward the mountains in a direction opposite to the flow of the streams which pass over them. Under the above conditions it is obvious that all the water derived from the melting snow of the Lewis Range must either be carried along the valleys of these various streams as a surface flow or an underflow, or be absorbed by the local glacial deposits which cover the formations along the base of the Lewis Range.

From the above it is apparent that the structural relations of the geologic formations in the plains region bordering the Lewis Mountains, including Sun and Teton river valleys, are unfavorable for the occurrence of deep-seated artesian water. Small areas with artesian water of local origin are, however, scattered through this district. Along Muddy Creek, a tributary of Teton River, there is a small district, comprising about 20 square miles, in which a number of successful artesian wells have been obtained. The depth of these wells varies from 16 to 100 feet. The water is relatively pure and is used for both domestic and irrigation purposes. It is obtained from a coarse gravel bed, which is overlain by glacial clay of variable thickness. This artesian area is believed to be supplied with water from the stream in Ralston Gap and upper Muddy Creek. These streams contain numerous swamps in their upper courses, but the water in passing downstream sinks to an underflow a few miles above the artesian area, where it apparently passes under the impervious glacial clay and becomes available as artesian water when this impervious overlying clay is penetrated by well borings. In the lower part of Sun River valley, between Sun River and Great Falls, there are a few shallow wells. The flow of these wells is due to local artesian conditions, which extend over only small areas. The water is obtained in each case from gravel lying in the lower part of the valley filling. This gravel is locally covered by impervious clay, thus producing artesian conditions.

WATER SUPPLY BY DISTRICTS.

GEYSER DISTRICT.

Throughout the area lying to the east of Otter Creek divide the underground water supply is derived mainly from springs, which occur at varying intervals along nearly all of the mountain streams. These springs are more or less numerous in the region adjacent to

the inclosing mountain ranges, as is shown by the water-resource map (Pl. VII), but farther out on the plains they are fewer in number. Shallow wells occur here and there along the stream valleys. They vary in depth from 15 to 25 feet and afford an ample supply of good water, but owing to the large number of springs only a few wells have been sunk. Throughout this district the prospects for artesian water along Lonetree, Arrow, Surprise, Running Wolf, Skull, and Sage Creek valleys are very favorable. The region, as previously stated, is underlain by beds of porous sandstone belonging to the Kootenai formation, which in their outcrop area bordering the Little Belt Mountains absorb more or less water from mountain streams. In their extension northeastward these sandstone beds pass under impervious Colorado shale producing ideal artesian conditions. The Kootenai rocks underlying this region contain a bed of workable coal which has been prospected extensively and is mined at present at several localities. In 1901 the Sand Coulee Mining Company made extensive diamond-drill borings in search of coal along Sage Creek valley. Five holes were bored, ranging in depth from 400 to 700 feet, three in Sage Creek valley in T. 15 N., R. 12 E., one in a small tributary of Willow Creek near Hughes's ranch, and one about 3 miles east of Sage Creek Sheep Company's home ranch. A flow of good water was reported from each of these borings; the largest flow, however, was secured at Sage Creek Sheep Company's home ranch. The water from this well is stored in a small reservoir and used for irrigation purposes. According to the best information which could be obtained concerning these borings, the water in each case was derived from a gray sandstone, probably constituting one of the basal members of the Kootenai formation. The occurrence of these artesian wells in upper Sage Creek valley has a very important significance, for it demonstrates that artesian water can be secured at moderate depths throughout the upper courses of several small mountain-stream valleys in the immediate vicinity, an area comprising a considerable acreage of rich agricultural land. The prospects for artesian water are equally favorable in the upper part of the Skull Creek valley for a short distance northeast of Skull Butte, and it is possible that small flows might be obtained throughout the wide valley of Running Wolf Creek in the vicinity of Stanford. While no practical tests have been made of the artesian water capacity of the Kootenai sandstone underlying Lonetree Creek valley in the vicinity of Geyser, the geologic conditions in this district are favorable for flowing wells. The porous sandstone of the Kootenai formation dips gradually northeastward away from the Little Belt Mountains, passing under the impervious Benton shale, which in the vicinity of Geyser and along Lonetree Creek valley could be penetrated by relatively shallow borings.

110° 15' R. 12 E.

OTTER CREEK DISTRICT.

The Otter Creek district is arbitrarily taken to include the area between Otter Creek divide and Belt Creek. It has an abundant water supply, which is derived largely from springs. A few shallow wells are found along Belt Creek valley and its tributaries, especially in the vicinity of Belt. Shallow wells are also not infrequent on the higher slopes bordering the Highwood and Little Belt mountains. Along Otter Creek numerous springs from the Kootenai sandstone occurring at frequent intervals either in the bottom of the valleys or on the sides of the bluffs furnish an ample amount of good water and make it generally unnecessary to sink wells. The tributaries of Otter Creek from the south, which drain the high plateaus, are also well supplied with spring water from the same source. North of Otter Creek, especially on the higher slopes bordering the Highwood Mountains, there is a strong underflow in the bottom of all the coulees, which is derived from melting snow higher on the mountain slopes. The water thus absorbed in the heads of the coulees high on the slopes appears at the surface lower down in their course in the form of small springs, or it can be easily reached by shallow wells.

GREAT FALLS DISTRICT.

Under the Great Falls district is described the territory lying south of Missouri River between Belt Creek and Smith River. As stated above it is essentially a plateau region more or less dissected by canyons. Throughout the lower part of the district, on the plains east of Great Falls, water for domestic purposes is apparently difficult to obtain, excepting along Box Elder Creek valley, where a number of shallow wells furnish a large amount. Several wells have been dug by the Great Falls Meat Company immediately east of Great Falls. The depths of these vary from 150 to 300 feet, and in no instance has the quality and quantity of the water been entirely satisfactory. Farther to the south and east springs are the chief source of water supply, although a few wells have been sunk. As a rule wells in this portion of the district are not successful, and it is believed that the most satisfactory source of domestic water supply is to be found in the development of the small springs which are more or less abundant. At Stockett and Sand Coulee a few wells have been bored, which are described on page 70, and on the high plateaus southeast of these towns deep borings have been made, which usually failed to secure a satisfactory amount of water. In the vicinity of Stockett there is a local doming of the formations, which exposes the Madison limestone for a considerable distance along Sand Coulee and in Cottonwood and Straight coulees. Wells sunk in this limestone fail to find water, for the upper part of the formation is not water bearing. The Jurassic and Cretaceous formations overlying the Carboniferous limestone

in this vicinity are relatively thin, but they thicken to both the east and the west. Wells bored on the plateaus penetrate the water-bearing sandstone of the Kootenai formation within a distance of 200 to 300 feet from the surface. This sandstone in the vicinity of Stockett and Sand Coulee is not heavily saturated with water, notwithstanding that it is the source of many small springs. The scarcity of water is probably due to the fact, as previously described, that in its southern extension the sandstone caps the higher hills, where the only water which it can absorb is from rainfall and melting snow. In sinking a well in this general region whenever the limestone is reached the boring should be discontinued, for it indicates that all the water-bearing rocks of the region have been penetrated. Along the west side of the district, where the plateaus are capped by the basal sandstone of the Colorado, springs are abundant along the side of the plateaus (see Pl. V, A), and in the valleys good water is obtained from shallow wells. Representative wells and springs in the Great Falls district are listed on pages 43-44 and 53-55.

MISSOURI RIVER VALLEY DISTRICT.

Along Missouri River valley from the base of Big Belt Mountains to a point about 2 miles above Riverdale there is a wide, open valley on the east side of the river in which an abundance of good water is obtained from wells at depths varying from 15 to 25 feet, depending on the distance from the river. A few wells in this valley have been sunk to greater depths in order to obtain a larger supply of water, but generally they have not been successful. Several unsuccessful attempts have also been made to secure artesian water in the valley. This is not practicable, owing to the adverse structural relations described on page 27. The water of shallow wells is derived from alluvial sands and gravel, which have a variable thickness. To the east, on the summit of the high plateau bordering Smith River on the west, water is secured from wells at a considerably greater depth. Here the principal water-bearing horizon is the basal sandstone of the Colorado formation. Wells along this plateau vary from 50 to 150 feet, and a sufficient quantity of water is usually obtained. The extent of the basal Colorado sandstone in this region is shown on the geologic map (Pl. I).

ULM BENCH.

Throughout Ulm Bench, which lies southwest of Great Falls between Missouri and Sun rivers, dry farming is extensively practiced, and the district has been divided into a number of small farms. On these farms wells have been bored which invariably obtain good water at depths rarely exceeding 100 feet. The water is derived from the lower part of the basal Colorado sandstone which caps Ulm Bench. Along the western margin of Ulm Bench, where the over-

lying Colorado shale occupies the surface, the well water is generally more or less mineralized and unfit for domestic purposes.

AREA SOUTH OF SUN RIVER.

West of Ulm Bench throughout the district lying south of Sun River the prospects for underground water are not favorable. The formation occupying the surface in this region is the Colorado shale, which rarely if ever contains pure water. The principal drainage of the area is Little Muddy Creek, a large intermittent stream draining a considerable district south of Square and Fort Shaw buttes. From several field analyses which have been made of water from wells in this valley it has been found to contain an unusually large amount of magnesium and other harmful salts. The well water in this region is so highly mineralized that it is rendered unfit even for stock purposes. The Eagle sandstone, which with the overlying igneous rock caps the prominent buttes in this region, is the only near source of potable water supply.

West of Crown Butte throughout the lower part of the territory drained by Sims Creek prospects for underground water are more favorable. Here the Eagle sandstone underlies the surface, and, while no practical tests have been made, it is believed that wells sunk in this sandstone will probably secure good water.

SUN RIVER VALLEY.

Along the valley of Sun River water for domestic and stock purposes is derived from wells and springs or taken directly from the river. In the lower part of the valley between Sun River and Great Falls many shallow wells have been sunk which furnish a good supply. These derive their waters mainly from the valley wash. Farther up Sun River valley throughout the lower land water is obtained from shallow wells, but back from the streams the depth increases. At Fort Shaw a well was recently drilled and good water found at a depth of 101 feet. This, however, was at the mouth of a small coulee entering Sun River from the south, and it is possible the well did not penetrate the valley filling. In the vicinity of Augusta water is secured from wells at depths varying from 10 to 15 feet, but here the greater part of the domestic water supply is taken directly from Sun River, where, owing to the nearness to Lewis Mountains, it is relatively pure. The prospects for water from deep wells in Sun River valley are very poor, especially in the lower part. Between Manchester and Sims well borings extending through the valley filling will enter the nonwater-bearing Colorado shale, which has a thickness increasing from zero at Manchester to over 800 feet at Sims. Between Sims and Augusta wells sunk below the bottom of the valley

filling would enter the lower part of the Montana, which consists of sandstone and shale in alternating succession. The basal sandstone, comprising the Eagle formation, probably contains water, but the shale overlying the sandstone is believed not to be water bearing.

HIGHLANDS NORTH OF SUN RIVER.

Throughout the high plateau region between Sun and Teton rivers the prospects for underground water are not generally favorable. On that portion of the region lying west of Freezeout Lake no wells, so far as could be ascertained, have been bored which would test the water capacity of the extensive gravel terraces capping the highland, but it is evident from the numerous springs along their eastern margin that they contain more or less water. Underneath the gravel of this district occur the Eagle and Claggett sandstones, which are also water bearing, so that it is believed little difficulty would be encountered in securing a good supply of water from wells in this part of the field. On Freezeout Bench, however, a number of shallow wells have been sunk, which, with one exception, do not furnish a satisfactory amount of water. At Zimmerman's ranch a well 30 feet deep supplies only a small amount of alkali water, while 3 miles to the southwest, at Kruck's ranch, a good well of potable water was secured at about the same depth. Freezeout Bench is composed geologically of a thin veneer of gravel lying on the nonwater-bearing Colorado shale, consequently the only water which can be expected from wells on this bench is at the base of this gravel, which has a thickness varying from 25 to 40 feet. The amount of water available at the base of the gravel will probably not be large, although this may vary locally, and in many cases it is apt to be hard, as the gravel carries considerable lime as a cementing material. Wells penetrating the gravel and entering the Colorado shale would probably obtain alkali water, as this shale rarely furnishes good water. North of Freezeout Bench in some of the coulees tributary to Muddy Creek of Sun River there are small springs fed by the gravel terraces, and here and there a successful shallow well.

FORT BENTON BENCH.

East of the Montana and Great Northern Railway, between Great Falls and Collins, is an area of featureless plains comprising several townships and locally known as Fort Benton Bench, in which the prospects for underground water are very poor. Although this area was not examined in detail, it is known that over a great part of the district the surface formation is Colorado shale. The results of the Banatyne boring, 6 miles east of Dutton, demonstrate that the surface formation and the formations underlying to a depth of at least 1,500 feet are not water bearing. Along Teton Valley, which crosses the

northern part of the district, shallow wells can probably be obtained from the valley wash, although no detailed examination was made of this portion of the field, and it is believed that shallow wells furnishing a moderate supply of water could be secured in some of the small coulees draining northwestward into Teton River.

TETON RIVER VALLEY.

From the west margin of T. 25 N., R. 6 W., eastward as far as the investigation was carried, and especially to the mouth of Deep Creek, there is a strong underflow in Teton Valley. Wells at Chouteau obtain water at three distinct horizons, the first at 7 feet, the second at 27 feet, and the third at 48 feet beneath the surface. There is no marked dissimilarity in the chemical character of the water found at these depths, and in many respects it resembles the water of Teton River. Springs occur in abundance in Teton Valley above Chouteau.

Deep Creek Valley, a tributary of the Teton from the south, has a strong underflow, and an abundance of water is found at depths of 10 to 20 feet below the surface. At the head of Deep Creek are numerous small swamps and glacial lakes, which add materially to both the surface flow and the underflow of Deep Creek valley. North of Deep Creek there is a wide gravel-capped terrace extending toward the mountains, throughout which water could probably be secured from wells not exceeding 30 feet in depth, the water occurring at the base of the gravel. North of this broad terrace there is a badlands district surrounding Teton Buttes, in which there is a scarcity of water.

BURTON BENCH.

Springs are not abundant in the vicinity of Chouteau outside of Teton River valley, and water for domestic purposes is sometimes difficult to obtain. An exception is found in Burton Bench, an area comprising about four townships, which lies north of Chouteau. Bench gravel, loosely cemented, caps this area, thinning gradually from a depth of 30 feet on the southwest to a mere sprinkling on the northeast. Immediately beneath this cap is impervious shale, causing the gravel to act as a reservoir for surface water. Before irrigation ditches had crossed Burton Bench water was obtained at a depth corresponding to the thickness of the gravel, but the water plane has been gradually rising under the influence of irrigation until now an abundant supply is found at 10 to 12 feet beneath the surface. Outside the gravel-capped area water for stock and domestic purposes is taken directly from the ditches, although it contains a considerable quantity of undesirable mineral matter. The average well has a depth of about

60 feet, but is often too strongly impregnated with alkali to be potable. A limited artesian basin of about 20 square miles occurs in the northeastern part of Burton Bench. It is described in detail in the next section.

MUDDY CREEK ARTESIAN BASIN.^a

General description.—Within an area extending about 6 miles west from where the terminal moraine of the Keewatin ice sheet crosses Muddy Creek valley in T. 25 N., R. 3 W., and having a width of about 3 miles, artesian water is obtained from coarse granitic gravel, overlain by impervious lacustrine clay, at moderate depths below the surface. The writer examined twenty-two flowing wells in this district, all of which furnish a good quality of water. Others that formerly flowed have become clogged by caving where the well was not cased.

The water resources of this basin have not as yet been utilized to any great extent, partly because much of the area is used only for grazing and partly because water for irrigating purposes is readily available from the ditches crossing Burton Bench. In many cases the water is allowed to flow from the wells and no use is made of it, but in many instances outside of the ditch system it is utilized for irrigation as well as for stock and domestic purposes. Two wells in sec. 6, T. 25 N., R. 3 W., water 30 acres of alfalfa, and a group of wells in sec. 11, T. 25 N., R. 4 W., irrigate 100 acres of hay land. In general the wells are 2½ or 3 inches in diameter, as it was found by experiment that a pipe of that size yielded the same flow as a larger one. The smaller size is the more advantageous, since wells of that diameter may be drilled by hand where the depth does not exceed 75 or 80 feet. The method of drilling used in this vicinity is simple. A 1-inch iron rod twisted at one end into a spiral of the diameter desired is used as an auger. The stiff clay which must be penetrated is sufficiently adhesive to allow the drill to bring up a clean core several feet in length. The wells vary in depth from 16 to 100 feet, the deeper being as a rule along Muddy Creek. The variation in depth of these wells indicates that this stream is following rather closely its preglacial channel. Although practically all the artesian wells are south of Muddy Creek, it is probable that there is likewise a considerable area north of that stream where flowing wells might be obtained if, as seems probable, the preglacial valley extends laterally in that direction as well as south. The eastern limits of the basin are defined by the moraine, and since the head of the artesian flow is in no case great, the largest reported being 35 feet, it is not probable

^a The description of artesian conditions in the Muddy Creek artesian basin is by W. R. Calvert.

that a flow can be secured much farther west than the wells located in sec. 15, T. 6 N., R. 4 W., where the pressure is very weak.

Source.—Brief mention has already been made (p. 61) of the probable source of the artesian water of Muddy Creek basin. The geologic structure of the region and the small head of the flowing wells preclude the theory of a distant or high source. That the artesian flows of this area are due to local conditions is evident from a study of the field. Some water may be supplied by Muddy Creek in its course through T. 26 N., R. 6 W., where the water sinks to an underflow, leaving the stream bed dry for a distance of several miles during the greater part of the year. Since apparently the entire flow reappears at the surface near Bynum, and the stream has not there cut through the lacustrine clays, it is not probable that Muddy Creek contributes much of the artesian water to Muddy Creek basin. On the contrary, the evidence indicates that the artesian basin is connected more directly with the Teton through Ralston Gap. To the observer looking southwest through Ralston Gap it seems probable that the depression was once a large stream valley, and since river sand and gravel are found there the conclusion is further strengthened. From the base of the mountains until it reaches the southeast corner of T. 25 N., R. 6 W., Teton River is not intrenched, but flows in a wide gravel-filled valley. Considerable water is absorbed by this gravel, and it is believed that there is an underflow from Teton River through Ralston Gap to Muddy Creek valley. Springs in sec. 16, T. 25 N., R. 6 W., vary in their flow with the flow of Teton River, the rise in the river increasing within a short period of time the flow of the springs. This phenomenon has been observed even during the dry season of the year, hence it is difficult to attribute this increase in the flow of the springs to any other source than the increase of Teton River. A small stream north of Teton River at present flows toward Ralston Gap, but as it reaches the vicinity of the gap it sinks to an underflow and probably soon passes beneath the impervious lacustrine clay into the porous granitic gravel and becomes available as artesian water to the east when the overlying impervious clay is penetrated by well borings.

WATER SUPPLY OF TOWNS AND VILLAGES.

There are comparatively few towns in the Great Falls region. Great Falls, the largest, derives its city water supply from Missouri River about 1 mile above the business center. From the pumping station, which is located in the NW. $\frac{1}{4}$ sec. 14, T. 20 N., R. 3 E., the water is pumped directly to a standpipe, located on a prominent hill in the eastern part of town, which has a capacity of 560,000 gallons. From this point it is distributed by a system of 6-inch mains to the

different parts of the city. A field assay of the water taken from one of the hydrants in the main part of the city is as follows:

Analysis of a sample of the Great Falls city water.

[Parts per million.]

Source	Missouri River.
Color	0
Iron	0
Total hardness	125
Alkalinity	180
Alkaline carbonates	32
Alkaline-earth carbonates	160
Chlorides	25

Chouteau, the next town in importance within the district and the county seat of Teton County, depends entirely upon shallow wells for its water supply. Here water is obtained from valley filling at three distinct horizons, which, as previously stated, occur at depths below the surface of 7, 27, and 48 feet, respectively. The largest supply is usually found at a depth of 7 feet below the surface, but wells are generally sunk to the lower horizons in order to obtain water less liable to surface contamination. There is no general town system.

The water supply for the town of Sand Coulee is derived from wells which show considerable variation in depth. In the valley wells are considerably over 100 feet deep. The well owned by Louis Dahn, situated in the valley in the northern part of town, is 168 feet deep. On the slope of the hills bordering the valley water has been secured at depths of 25 to 30 feet, but the supply is variable. In the sides of some of the small coulees in the vicinity of this town there are many water seeps, as previously described, which if properly developed might afford a good domestic water supply.

Considerable difficulty has been encountered in obtaining water for the town of Stockett. In the northern part of the town the people depend for water largely on small springs issuing from the base of sandstone in the sides of the coulee. It has been found by experiment that these small seeps in the hillside, when properly developed, often furnish a good steady flow of potable water. Farther up the coulee, in the main part of town, the Cottonwood Coal Company has sunk a well in the bottom of the main coulee to a depth of 50 feet. From the bottom of this well a tunnel 4 feet wide by 5½ feet high has been dug 90 feet to the east and 125 feet to the west, thus obtaining the greater part of the underflow of the coulee in which Stockett is built. During the driest season of the year the well has furnished 65,000 gallons per day, and the average capacity is over 100,000 gallons a day, most of which is used by the

Cottonwood Coal Company. Wells sunk in the sides of the coulees furnish small quantities of water at varying depths.

The present supply of water for both Sand Coulee and Stockett might be materially increased by the proper improvement of the numerous moist places occurring along the sides of many of the coulees. These moist places or seeps are generally indicated by the deeper green color of the vegetation. In many such localities if shallow excavations were made, water in considerable quantity would probably be obtained, which could easily be piped to houses situated in the valley, thus affording an excellent domestic water supply. The practicability of such a source of water has been demonstrated at a few places in the vicinity of Stockett and at many places along Otter Creek, where springs occur under similar conditions. It is believed also that on many of the small farms in the vicinity of Stockett and Sand Coulee a careful examination of the sides of the coulee might result in the location of moist or seepy places where by inexpensive development water could be procured.

CHEMICAL CHARACTER OF WATER.

During the course of the investigation of the water resources of the Great Falls region samples of water were collected from representative wells and springs for the purpose of analysis. These analyses or assays were made in the field in accordance with the method employed by the water resources branch of the United States Geological Survey. This method is fully described in Water-Supply Paper No. 151. Knowledge was also desired concerning the variation, if any existed, in the quality of waters from the several formations represented in the district. Although a complete analysis of the samples was not possible by the methods employed, the chief characteristics and chemical constituents were determined. These include physical properties, color and turbidity, and those depending more directly upon chemical quality, namely, the amount of iron, calcium, alkaline and alkaline-earth carbonates, sulphates, and chlorides present, and the hardness.

The waters throughout the district are remarkably free from turbidity, only one sample possessing more than a trace. In only a few instances was the presence of coloring matter noted, and iron is a rare constituent in the waters examined.

In the region east of Missouri River the great majority of springs issue from the sandstone or sandy shale of the Kootenai formation. In general the calcium and sulphate content of waters from this formation is high owing to the presence of gypsum in the shale. Near the southern border of the eastern portion of the district examined many springs issue from the Quadrant shale, and these are impregnated to a considerable extent with salts of magnesium and many are

charged with hydrogen sulphide, which renders them unpleasant for drinking. In the district where the surface formation is Colorado shale wells and surface springs are likewise apt to contain considerable magnesium and the alkalinity is high.

In the area west of the Missouri and south of Sun River, with the exception of Ulm Bench, water is relatively scarce and is obtained chiefly from the sandy members of the Montana. As above stated, the water of this district, especially in the Colorado shale area, is characterized by an abundance of magnesium salts, and the alkalinity is often so great as to render it unfit to drink. Several samples of wells and springs from this area also indicate the presence of a large amount of chlorides. In Sun River valley water is usually obtained from alluvium and is not so highly mineralized as that in the area to the south. To the north between Sun and Teton rivers but few samples were taken. There are few wells in this region and springs are not abundant. The samples analyzed, however, indicate that the various members of the Montana group afford water containing more or less mineral matter. In the valley of the Teton, where water is obtained from alluvium, the mineral content, while not especially high, is considerable. On Burton Bench the chief water supply is from the gravel capping consisting principally of limestone pebbles. This gravel contains a large amount of soluble salts. The chlorine content is especially high. In spite of the mineralization, however, it is of better quality than that from wells or springs in the region to the east, where the gravel capping is absent and Colorado shale occupies the surface. From the artesian basin in Muddy Creek valley two samples of water were analyzed. These samples show considerable variation. No. 1, from the eastern portion of the basin, is not so highly mineralized as No. 2, obtained farther west, the difference being chiefly in the calcium and sulphate content. The following table shows the results of the analyses of waters from the various parts of the area investigated. The results are expressed in parts per million.

[Parts per million.]

CHEMICAL CHARACTER OF WATER.

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No.	County.	Locality.	Township, etc.	Owner.	Source.	Quantity ^a	Temperature.	Turbidity.	Color.	Iron.	Calcium.	Total hardness as CaCO ₃	Total alkalinity as CaCO ₃	Alkaline carbonates as Na ₂ CO ₃	Alkaline earth carbonates as CaCO ₃	Sulphate radicle (SO ₄).	Chloride.
1	Teton	Chouteau	NW 1 NE. 1 sec. 6, T. 25 N., R. 3 W.	P. Eyraud	Artesian well.	Large	51	0	0	0	Mod.	69	249	0	249	181	19
2	do.	do.	SE 1 sec. 15, T. 26 N., R. 4 W.	I. Schmidt	do.	Medium		0	0	0	High	55	279	0	279	600+	5
3	do.	do.	SW 1 sec. 5, T. 24 N., R. 4 W.	W. W. Gamble	Well.	do.		0	0	0	Mod.	55	438	0	438	439	114
4	do.	do.	SW 1 SE. 1 sec. 25, T. 25 N., R. 3 W.	Hodgskiss	Teton River.			0	0	0	High	111	219	0	219	181	5
5	do.	do.	do.	do.	Well.			0	0	0	Mod.	111	199	0	199	159	10
6	do.	do.	SW 1 SE. 1 sec. 25, T. 24 N., R. 3 W.	do.	do.			0	0	0	Mod.	222	319	0	319	125	10
7	do.	do.	SW 1 sec. 19, T. 24 N., R. 4 W.	C. E. Moore	do.			0	0	0	High	83	438	0	438	431	27
8	do.	do.	SW 1 sec. 1, T. 24 N., R. 4 W.	H. R. Thompson	Spring	Small	50	0	0	0	High	83	359	0	359	573	79
9	do.	do.	SE 1 sec. 20, T. 23 N., R. 4 W.	F. Crossen	do.	Medium	52	0	0	0	Mod.	111	363	0	363	150	13
10	do.	Hepler	SE 1 SE. 1 sec. 35, T. 22 N., R. 3 W.	F. C. Knucks	Well.			0	0	0	Mod.	75	319	0	319	327	39
11	Cascade	Augusta	NE 1 sec. 2, T. 21 N., R. 5 W.	Flowerree	Spring			0	0	0	Mod.	83	279	42	239	191	19
12	do.	do.	Sec. 1, T. 21 N., R. 4 W.	do.	do.			0	28	0	Tr.	41	279	0	279	270	14
13	do.	Hepler	SE 1 sec. 4, T. 20 N., R. 3 W.	Flowerree's ranch	Well			0	0	0	Mod.	41	399	84	319	133	190
14	do.	do.	NE 1 sec. 4, T. 20 N., R. 3 W.	do.	Sun River			0	0	0	Mod.	69	319	0	319	235	10
15	do.	do.	NE 1 sec. 4, T. 20 N., R. 3 W.	Flowerree	Spring	Large		0	0	0	Mod.	69	279	0	279	222	19
16	do.	do.	NE 1 sec. 35, T. 20 N., R. 3 W.	Carl Meckel	do.	do.	48	0	0	0	Low	69	279	0	279	300	50
17	do.	Sun River	NE 1 sec. 34, T. 21 N., R. 2 W.	On government land	do.	do.	50	0	0	0	Mod.	111	319	0	199	196	10
18	do.	do.	NE 1 sec. 13, T. 19 N., R. 2 W.	Toman Bros.	Well.			100	0	40	Mod.	111	319	0	319	60+	239
19	do.	do.	NE 1 sec. 4, T. 20 N., R. 2 W.	do.	Spring	Large	52	0	0	0	Mod.	111	199	0	199	116	7
20	do.	do.	NE 1 sec. 22, T. 19 N., R. 1 W.	D. Reese	Well.			24	0	10	High	69	369	0	369	40+	109
21	do.	do.	NE 1 sec. 34, T. 21 N., R. 1 W.	M. T. Strong	do.			0	0	0	High	159	199	0	199	276	7
22	do.	do.	NE 1 sec. 30, T. 21 N., R. 1 W.	J. C. Adams	do.			0	0	0	High	90	259	84	199	150	19
23	do.	Great Falls	NE 1 sec. 7, T. 20 N., R. 3 E.	K. B. Melver	Spring.			0	0	0	High	90	259	0	259	237	14
24	do.	do.	SW 1 NE. 1 sec. 33, T. 21 N., R. 3 E.	Missouri River	Giant Springs	338 s. ft.		0	0	0	Mod.	97	339	0	339	300	10
25	do.	do.	NE 1 sec. 26, T. 20 N., R. 4 E.	Great Falls Meat Co.	Well			0	0	0	High	125	179	31	159	421	24
26	do.	do.	do.	do.	do.			0	0	0	High						13

^aSprings with a flow sufficiently large to fill a 2-inch pipe are regarded as large, those between three-fourths inch and 2 inches as medium, and those less than three-fourths inch as small.

Analyses of waters from Great Falls region, Montana—Continued.

No.	County.	Locality.	Township, etc.	Owner.	Source.	Quantity.	Temperature.	Turbidity.	Color.	Iron.	Calcium.	Total hardness as CaCO ₃ .	Total alkalinity as CaCO ₃ .	Alkaline carbonates as Na ₂ CO ₃ .	Alkaline earth carbonates as CaCO ₃ .	Sulphate radicle (SO ₄).	Chlorine.
27	Cascade	Sand Coulee.	Sec. 13, T. 19 N., R. 4 E.	Louis Dahn.	Well.		°F.	0	0	0	Mod.	83	199	84	119	362	29
28	do.	Stockett.	NW. 1/4 sec. 15, T. 18 N., R. 4 E.	Ed. Connelly.	Spring.			0	0	0	High	122	279	0	279	207	19
29	do.	do.	SE. 1/4 sec. 14, T. 18 N., R. 4 E.	Davale Culberson.	do.			0	0	0	Mod.	111	279	0	279	207	19
30	Teton	do.	NE. 1/4 sec. 17, T. 18 N., R. 4 E.	C. Jaekel.	Well.			0	0	0	Mod.	86	222	0	222	164	19
31	do.	Great Falls.	Sec. 11, T. 19 N., R. 5 E.	— Johnston.	Spring.			0	0	0	Mod.	86	222	0	222	35	19
32	do.	do.	SW. 1/4 sec. 12, T. 19 N., R. 5 E.	D. Johnston.	do.			0	0	0	Mod.	48	243	429	243	65	20
33	do.	do.	SE. 1/4 sec. 12, T. 19 N., R. 5 E.	Ray & Friedrich.	Well.			0	0	0	Tr.	48	364	0	324	28	19
34	do.	Stockett.	NE. 1/4 sec. 31, T. 18 N., R. 5 E.	Sheep Co.	do.			0	0	0	Mod.	122	279	0	279	150	39
35	do.	Belt.	NE. 1/4 sec. 16, T. 17 N., R. 6 E.	J. Miltach.	Spring.		45	0	0	0	Mod.	41	199	0	199	327	10
36	do.	do.	NE. 1/4 sec. 15, T. 18 N., R. 6 E.	P. Johnson.	Well.			0	0	0	High	97	239	0	239	201	14
37	do.	do.	SE. 1/4 sec. 22, T. 19 N., R. 6 E.	J. R. Bowen.	do.			0	0	0	Mod.	115	283	42	283	35	19
38	do.	do.	Sec. 21, T. 19 N., R. 6 E.	Chas. Lindsey.	do.			Tr.	0	0	Mod.	77	283	0	243	35	14
39	do.	do.	SW. 1/4 sec. 14, T. 19 N., R. 6 E.	do.	do.			0	0	0	Mod.	48	220	0	220	202	10
40	do.	do.	NE. 1/4 sec. 15, T. 19 N., R. 6 E.	F. Polutnik.	do.			0	0	0	Mod.	77	283	0	283	Tr	14
41	do.	do.	Sec. 15, T. 19 N., R. 6 E.	A. H. McMillan.	do.			0	0	0	Mod.	48	314	0	314	84	99
42	do.	do.	do.	Edgar Mann.	do.			0	24	0	Mod.	48	202	0	202	38	159
43	do.	do.	do.	do.	do.			0	0	0	Mod.	48	405	0	405	62	149
44	do.	do.	Sec. 8, T. 19 N., R. 6 E.	G. Erickson.	Spring.			0	0	0	Mod.	48	405	0	405	73	20
45	do.	do.	Sec. 5, T. 19 N., R. 6 E.	W. H. Porter.	do.			0	0	0	Mod.	57	243	0	243	29	10
46	do.	do.	NW. 1/4 sec. 3, T. 19 N., R. 6 E.	do.	Well.			0	0	0	Low	57	324	0	324	38	16
47	do.	do.	SE. 1/4 sec. 3, T. 19 N., R. 6 E.	Joe Bogner.	Spring.			0	0	0	High	67	141	0	141	222	29
48	do.	do.	SE. 1/4 sec. 35, T. 20 N., R. 6 E.	P. P. Buchanan.	do.			0	47	1	Mod.	83	279	0	279	112	17
49	do.	do.	SW. 1/4 sec. 26, T. 20 N., R. 6 E.	J. B. Long.	Well.			0	0	0	Tr.	83	279	0	279	112	17
50	do.	do.	Sec. 33, T. 20 N., R. 7 E.	— Glette.	do.			0	47	0	Mod.	48	324	0	324	600+	19
51	do.	Cora.	SW. 1/4 sec. 3, T. 18 N., R. 7 E.	F. Armstrong.	do.			0	52	0	Mod.	57	191	0	191	160	19
52	do.	Belt.	SW. 1/4 sec. 8, T. 18 N., R. 7 E.	T. D. Jocelyn.	Spring.			0	0	0	Mod.	57	202	42	162	80	12
53	do.	do.	NW. 1/4 sec. 10, T. 18 N., R. 7 E.	G. W. Blake.	do.			0	0	0	Low	46	445	21	425	286	10
54	do.	do.	NW. 1/4 sec. 18, T. 18 N., R. 7 E.	Chas. Ashwert.	do.			0	47	0	Mod.	38	121	0	121	56	14
55	do.	do.	NW. 1/4 sec. 21, T. 18 N., R. 7 E.	T. Armstrong.	do.			0	19	0	Mod.	57	220	0	220	84	10
56	do.	do.	SE. 1/4 sec. 30, T. 18 N., R. 7 E.	F. J. Ober.	do.			Tr.	0	0	Mod.	67	222	0	222	94	10
57	do.	do.	R. 7 E.	Bundy & Henderliden.	do.			0	0	0	Mod.	48	245	0	245	312	10
58	do.	do.	SE. 1/4 sec. 28, T. 17 N., R. 7 E.	J. Labole.	Well.			0	0	0	Mod.	48	245	0	245	324	10
59	do.	do.	NE. 1/4 sec. 4, T. 16 N., R. 8 E.	do.	do.			0	0	0	Mod.	48	245	0	245	324	10

58	do.	do.	NE. 1/4 sec. 19, T. 17 N., R. 8 E.	Bundy & Henderiden	Spring	Small.	0	0	0	0	28	406	0	40	Tr.	5
59	do.	Geyser	NW. 1/4 sec. 3, T. 17 N., R. 8 E.	— Larson	do.		0	0	0	High	57	293	0	293	384	10
60	do.	do.	NW. 1/4 sec. 28, T. 18 N., R. 8 E.	R. Williamson	Well		0	0	0	Mod.	67	139	0	139	96	14
61	do.	Belt	NE. 1/4 sec. 22, T. 18 N., R. 8 E.	A. A. Dawson	Spring		0	0	0	0	28	40	0	40	0	10
62	do.	do.	SW. 1/4 sec. 20, T. 18 N., R. 8 E.	J. W. Watkins	Well		0	0	0	Mod.	28	330	0	330	403	14
63	do.	do.	SW. 1/4 sec. 6, T. 18 N., R. 8 E.	do.	do.		0	0	0	Low	38	384	0	384	102	10
64	do.	Geyser	SW. 1/4 sec. 3, T. 18 N., R. 8 E.	C. W. McClay	Spring		0	0	0	High	77	40	0	40	492	10
65	do.	do.	SW. 1/4 sec. 9, T. 18 N., R. 8 E.	C. J. Ellis	do.		0	0	0	High	111	162	0	162	64	10
66	do.	do.	NE. 1/4 sec. 19, T. 17 N., R. 9 E.	G. L. Lee	do.		0	0	0	Mod.	83	202	0	202	73	7
67	do.	do.	NE. 1/4 sec. 12, T. 18 N., R. 9 E.	S. C. Philbrick	do.		0	0	0	Mod.	83	202	0	202	245	7
68	do.	do.	SW. 1/4 sec. 20, T. 18 N., R. 9 E.	D. Rankin	Well		0	0	0	High	83	202	0	202	600+	10
69	do.	do.	SE. 1/4 sec. 4, T. 18 N., R. 10 E.	B. Shannon	Spring	Large	46	0	0	Mod.	111	202	0	202	394	7
70	do.	do.	SE. 1/4 sec. 14, T. 18 N., R. 10 E.	J. A. O'Hara	do.	do.	41	0	0	Mod.	133	81	0	81	130	5
71	do.	do.	SW. 1/4 sec. 20, T. 16 N., R. 10 E.	J. H. Skelton	do.	Medium.	41	0	0	Mod.	134	364	0	364	364	5
72	do.	Stanford	NW. 1/4 sec. 13, T. 16 N., R. 10 E.	First National Bank	do.		0	0	0	Mod.	134	364	0	364	364	5
73	do.	do.	R. 10 E.	do.	do.	Small	45	0	0	High	27	324	0	324	574	7
74	do.	do.	SW. 1/4 sec. 34, T. 16 N., R. 10 E.	Burgess	do.	do.		0	0	Mod.	69	121	0	121	122	5
75	do.	do.	SE. 1/4 sec. 2, T. 15 N., R. 10 E.	Rutterfield	do.	do.		0	43	Mod.	69	121	0	121	174	5
76	Fergus	do.	NE. 1/4 sec. 11, T. 17 N., R. 11 E.	Bower Bros.	do.	do.		0	0	High	97	293	263	293	362	10
77	do.	do.	SE. 1/4 sec. 33, T. 17 N., R. 11 E.	do.	Well		0	0	0	Mod.	36	324	0	324	600+	17
78	do.	do.	R. 11 E.	do.	do.		0	0	0	Mod.	36	324	0	324	600+	17
79	do.	do.	NE. 1/4 sec. 24, T. 16 N., R. 11 E.	W. Skelton	Spring		0	0	0	High	83	223	0	223	238	10
80	do.	do.	SW. 1/4 sec. 10, T. 15 N., R. 11 E.	Bower Bros.	do.		0	0	0	Mod.	139	219	10	209	154	5
81	do.	do.	SE. 1/4 sec. 4, T. 15 N., R. 12 E.	B. E. Stacks	Well		0	0	0	High	83	259	0	259	313	7
81	do.	do.	NW. 1/4 sec. 23, T. 15 N., R. 12 E.	Sage Creek Sheep Co.	do.		0	0	0	Mod.	111	159	0	159	313	10

WATER POWER.

DESCRIPTION OF FALLS.

The water power of the Great Falls region is undoubtedly one of its most valuable assets, although at present it is practically undeveloped. Between the Great Northern Railway bridge at Great Falls and the mouth of Belt Creek, a distance of approximately 10 miles, Missouri River has a total fall of 612 feet. Of this amount the greater part occurs at five different places, Black Eagle, Coulters, Rainbow, Crooked, and Big falls, which are collectively known as the Great Falls of Missouri River. (See Pl. III, .1, *B*, and Pl. IV, *A*, *B*.) The remainder of the fall which takes place between the above-mentioned points is in the form of rapids occurring at varying intervals between the cataracts. Conflicting reports are current regarding the exact height of the different falls. According to the first measurements, which were made by Lewis and Clark in 1804, Black Eagle Falls have a drop of 20 feet, Coulters 14 feet 7 inches, Rainbow 47 feet 8 inches, Crooked 19 feet, and Big Falls 87 feet $\frac{3}{4}$ inch. In M. S. Parker's description of the falls, published in 1894, the following measurements are given, which are somewhat at variance with those above quoted, although in a previous article by Parker, published in 1892, favorable comment is made on the accuracy of the Lewis and Clark measurement. Parker ascribes to Black Eagle Falls a drop of 20 feet, to Coulters 14 feet, to Rainbow 37 feet, to Crooked 19 feet, and to Big Falls 75 feet 4 inches. No careful measurements of these falls were made by the author while in the field, but according to the best information which can be obtained from local engineers familiar with the region the height of Black Eagle Falls, the first of the series, located at the Boston and Montana smelters, is 41 feet, including the masonry dam, which has been built on their crest. Coulters Falls, which are about 1 mile farther downstream and just above the Great Northern Railway bridge, have a drop of 14 feet. A short distance below the railroad bridge and about one-eighth of a mile from Coulters Falls, are Rainbow Falls, which have a drop of 37 feet. Crooked Falls, so named from their irregular shape, which occur about one-fourth of a mile farther downstream, drop 20 feet, and 4 miles still farther down the Missouri the water at Big Falls plunges over a precipice 75 feet high. Views of Black Eagle, Rainbow, Crooked, and Big falls are shown in Pls. III, *A*, *B*, and IV, .1, *B*, respectively.

UTILIZATION.

At present power from only Black Eagle Falls has been developed. The Boston and Montana Smelter Company have constructed a large masonry dam which develops sufficient power, supplemented by an

auxiliary steam plant, to supply the large smelters owned by that company on the north side of Missouri River at this place. The amount of horsepower developed at Black Eagle Falls varies from 6,000 to 12,000, depending on the season. In addition to the large power plant located on the north side of the river there is also a smaller power plant on the south side, which is used as an electric station for power for street railways, electric-light plant, Royal Milling Company's flour mills, and a number of smaller factories.

UNDEVELOPED POWER.

Coulters, Rainbow, Crooked, and Big falls are wholly undeveloped, although they are apparently more favorably situated for power development than Black Eagle Falls. The following table shows the available horsepower of the different falls:

Available horsepower of the Great Falls of Missouri River.

Name.	Height.	Discharge.	Horsepower.
	<i>Feet.</i>	<i>Second-feet.</i>	
Black Eagle Falls.....	41	1,800	6,545
Coulters Falls.....	14	2,400	3,272
Rainbow Falls.....	37	2,400	8,072
Crooked Falls.....	20	2,400	4,333
Big Falls.....	75	2,400	16,368
			38,585

The above statements are based on a minimum flow of Missouri River above Black Eagle Falls of 1,800 second-feet, as shown by Government discharge measurements extending over a period of four years, from 1902 to 1905, inclusive. These measurements were taken at Cascade, where the Geological Survey has maintained a gaging station for a number of years. To the measurements of this gaging station is added an average minimum flow of Sun River, which empties into the Missouri a short distance above Great Falls and between Cascade and Black Eagle Falls. Below Black Eagle Falls Giant Springs add to the flow of the river approximately 600 cubic feet per second, which apparently does not vary at different seasons of the year. Taking this amount into consideration Coulters, Rainbow, Crooked, and Big falls would have a minimum flow of about 2,400 second-feet. This amount has been used for calculating the available horsepower at these cataracts. Of course it should be borne in mind that by the proper development of any one of these falls the amount of available horsepower could be materially increased. It is possible also that by constructing suitable dams the fall of the numerous small rapids which occur between the cataracts could be made to furnish considerable power, but as such questions depend entirely on the nature and extent of the development, no esti-

mate as to the total horsepower which could be developed under ideal conditions of improvement in the vicinity of Great Falls is here given.

IRRIGATION.

GENERAL STATEMENTS.

Irrigation has been practiced along the valleys of the larger streams in the Great Falls region for many years, but its growth and development have been necessarily slow until recently. Prior to the building of railroad lines into the district, which was in 1886, and for some time afterwards, the inhabitants of the region were principally engaged in cattle raising and mining, and only small tracts were irrigated here and there along the valleys. With the growth in population and the increased demand for agricultural produce, irrigation began to be more generally practiced along the larger streams, resulting eventually in the construction of several large canals by private individuals or small companies organized among the ranchmen. Extensive preparations are now being made, both by the Government and by private enterprises, to reclaim larger tracts of land along Sun and Teton rivers and the highland lying between these two streams. (See Pl. VII.)

SUN RIVER VALLEY.

Sun River valley is one of the most extensively irrigated valleys in the Great Falls region. There are a large number of small ditches covering the lower lands along each side of the river from the vicinity of Great Falls to the base of the Lewis Mountains. In addition to these several large canals have been constructed by individual ranchmen and small companies organized among the farmers. The largest of these is the Flowerree Trustee ditch, which is taken out of North Fork of Sun River near the center of sec. 20, T. 21 N., R. 6 W., and extends for about 25 miles eastward, covering a large territory of table-land bordering Sun River on the north. Another and somewhat smaller ditch occurs on the same side of Sun River farther downstream, known as the Sun River canal. Its headgate is located near the east end of old Fort Shaw Reservation, and it furnishes water to an area nearly a mile in width, extending east as far as Muddy Creek of Sun River. One of the largest canals on the south side of Sun River is the Crown Butte canal, constructed by individual enterprise, which leaves the river in the southeast corner of sec. 6, T. 20 N., R. 4 W., and extending eastward crosses Sims Creek in a big loop, and passing through a low divide north of Crown Butte empties into the head of Little Muddy Creek valley. A number of smaller ditches are found along the south side of the river, including, from east to west, Campbell, Eder, and Richling Company, Bickel Burk,

Butler, Clemens, Phyllip, Mayer, and others farther up South Fork of Sun River. The Government irrigation project along the south side of Sun River, known as the Fort Shaw canal, covers about 16,000 acres in the vicinity of the Fort Shaw Reservation. The larger features of irrigation along Sun River valley are shown on the map (Pl. VII).

TETON RIVER VALLEY.

Irrigation is not extensively practiced along the valley of Teton River in the vicinity of Chouteau. A few small farms are irrigated around Chouteau and near the head of Spring Creek, but, with these exceptions, irrigation is confined to Burton Bench, where a number of large canals have been constructed. Burton Bench, which is one of the largest, if not the largest, irrigation district in the area described, is supplied with water by three large canals, the Burton, Cooperative, and Eldorado canals. These canals are all taken from the Teton River 10 miles above Chouteau. Their approximate location and the land irrigated by them is shown on Pl. VII.

The Cascade Land Company's ditch, which is taken out of Deep Creek on the south side about 3 miles above its mouth, extends around the east side of Priest Buttes, crosses by siphon flume the north end of Freezeout Basin, and continues to the Cascade Land Company's home ranch, where it furnishes water for several hundred acres of land situated in the southwestern part of T. 23 N., R. 3 W. A short distance below the headgates of the Cascade Land Company's ditch there is another ditch which is owned by the S. T. Cattle Company. It extends down the river about 6 miles, where it supplies water for over a thousand acres of land in T. 24 N., Rs. 3 and 4 W. The location of the above-described ditches and the approximate limits of the land to which they supply water are shown on Pl. VII.

OTHER VALLEYS.

Along the east side of Missouri River in the vicinity of Cascade, irrigation has been practiced for many years. No large canals have been constructed in this region, but a number of small ditches carry water some distance out from the river to scattered ranches along the valley. In Smith River valley are a number of irrigated ranches, but only a relatively small portion of the valley land is now cultivated. Hound Creek, one of its principal tributaries from the west, has a few small irrigated ranches along its course. Considerable irrigation is carried on all along Belt and Otter Creek valleys. No large canals have been built along these streams, owing mainly to the fact that the valleys are narrow and the amount of irrigable land small. Short ditches which occur at frequent intervals supply

water to small fields. Throughout the eastern portion of the district the streams carry only a small flow of water, all of which has been appropriated for irrigation purposes. In some cases private reservoirs have been constructed to increase the available supply by storing flood waters.

AGRICULTURE.

Throughout the lower Plains portion of the Great Falls region the aridity of the climate renders tillage without irrigation impracticable, but in the plateau region bordering Little Belt and Highwood mountains dry farming is extensively practiced far up the slopes of these ranges. The cultivated portions of the area examined comprise a relatively small part of the entire district, the remainder being utilized for pasturage of cattle—an important industry of the region, to which the upland areas are well adapted. Among the chief agricultural products are wheat, oats, barley, rye, spelt, flax, alfalfa, tame hay, potatoes, and a variety of garden vegetables, most of which are consumed by workers in the mines and smelters surrounding Great Falls. The main crop is wheat, which has a yield varying from 20 to 40 bushels per acre. Both winter and spring wheat is raised, but the preference seems to be for winter wheat at present. Oats have a large yield, ranging from 35 to 45 bushels per acre, and the yield of potatoes and other vegetables is unusually large.

Cascade County, Mont., is one of the most important grain centers in the State. Fruit raising is a growing industry, and many young, well-kept orchards are to be found throughout the district; currants, gooseberries, and strawberries are among the important fruits. The seasons are ordinarily of sufficient length to insure the maturity of all cultivated crops, except on the higher slopes bordering the inclosing mountain ranges, where the time between killing frosts is short.

The distribution and extent of the land irrigated, also the area in which dry farming is practiced, are shown on Pl. VII.

CLIMATE.

TEMPERATURE.

General statements.—The temperature records of this general region present a very wide range between extremes—a feature which is apt to cause an erroneous impression. Though the annual range is probably as large as in any other part of the United States, the periods of low temperature are of short duration and are generally attended by dry, calm atmosphere. Under these conditions the low winter temperatures are not so severe on life in general as much higher temperatures would be under less favorable conditions. Owing to this fact stock can successfully winter on the range without shelter. The summer temperatures, although high, are not so oppressive as an equivalent temperature would be in more humid atmosphere in

low altitudes. The summer days are long and often very hot, but as evening approaches the air cools rapidly by radiation, and the nights are cool and comfortable.

Great Falls region.—Very few meteorological data are available regarding the mountainous districts surrounding the Great Falls region, but there are a number of places lower down on the plains where systematic observations have been carried on for a number of years. The first meteorological station was established at Chouteau in 1890, and in December of the following year a similar station was placed at Great Falls. The observations begun at Chouteau were continued for only one year, but the station was reestablished at this place in January, 1905. Climate data began to be collected in a systematic way at Sun River in March, 1895, and a station was established at Augusta in July, 1896. Records of the temperature have been collected at Cascade, Mont., since May, 1894, but observations during the first two months are not quoted below. At Great Falls, where the most systematic information has been procured, and where the results are in a measure representative of the district, the mean monthly temperatures from 1893 to 1903, inclusive, are as follows:

Mean monthly temperatures for ten years at Great Falls, Mont.

	°F.		°F.
January -----	26	July -----	68
February -----	26	August -----	67
March -----	32	September -----	56
April -----	45	October -----	49
May -----	55	November -----	33
June -----	62	December -----	30

Throughout the above-described period the mean of the maximum temperatures at Great Falls varied from 36° in January to 83° in July. The absolute maximum temperatures range from 60° in December to 106° in August, the mean of the minimum from -14° in January to 54° in July, and the absolute minimum from -38° in January to 35° in July.

Although the climatic observations made at Great Falls may be regarded as in a measure representative of the district, yet for the purpose of comparing the variations between stations located near the base of the mountains and those farther out on the plains, the following comparative table is introduced. The highest temperature ever recorded at the Great Falls station is 106°, which occurred in August, 1892. The minimum temperature recorded was -38° in January, 1893. The average date of the first killing frost in autumn is in the latter part of September, while the average date of the last killing frost in spring is about the first of May. The direction of the prevailing wind is southwest, except in June, when it is west.

Comparative temperatures (°F.) at Augusta, Great Falls, Cascade, and Chouteau for five years (1902-1906, inclusive).

	Maximum.					Minimum.					Mean.				
	1902.	1903.	1904.	1905.	1906.	1902.	1903.	1904.	1905.	1906.	1902.	1903.	1904.	1905.	1906.
January:															
Augusta.....	58	63	54	55	60	-30	-14	-10	-28	-26	23.9	31.0	27.4	18.2	28.2
Great Falls...	60	56	52	47	53	-23	-2	-7	-21	-24	27.6	31.8	29.4	18.2	29.2
Cascade.....				56					-21	-28				19.4	
Chouteau.....					61					-21					28.5
February:															
Augusta.....	58	55	54	65	63	-19	-21	-20	-43	-14	26.6	24.0	15.8	18.6	29.2
Great Falls...	60	55	52	62	55	-16	-18	-16	-30	-10	27.5	25.9	15.1	20.2	30.1
Cascade.....				63	60				-38	-9				22.3	33.0
Chouteau.....				64	63				-34	-10				19.9	30.0
March:															
Augusta.....	55	62	58	70	70	-16	-13	-21	-7	-35	29.2	25.7	22.8	37.0	23.2
Great Falls...	56	63	45	71	68	-6	-7	-13	9	-24	35.0	27.2	16.6	40.8	26.2
Cascade.....				75	72				1	-31				42.0	27.2
Chouteau.....				69	71				6	-28				37.8	24.3
April:															
Augusta.....	66	72	79	73	86	15	10	16	4	14	39.8	39.5	44.8	41.2	45.6
Great Falls...	68	72	72	74	82	20	20	20	19	25	43.7	43.8	48.2	44.6	49.0
Cascade.....				76	86				14	20				45.5	50.8
Chouteau.....				72	85				11	22				41.6	47.4
May:															
Augusta.....	86	84	77	78	85	25	24	20	26	19	50.8	47.2	49.5	46.6	46.6
Great Falls...	86	89	82	78	87	30	27	30	31	30	56.2	51.0	54.2	50.6	50.1
Cascade.....				82	88				28	28				51.3	51.0
Chouteau.....				81	90				25	22				47.2	48.6
June:															
Augusta.....	83	86	90	83	82	27	32	32	30	30	53.2	60.0	56.4	53.8	53.0
Great Falls...	86	87	94	88	80	34	40	41	35	40	57.4	65.0	62.0	58.0	57.7
Cascade.....				88	85				33	37				58.4	59.4
Chouteau.....				84	80				31	35				55.6	55.4
July:															
Augusta.....	87	93		91	88	36	34		31	38	59.9	60.0		67	63.4
Great Falls...	92	92		97	93	42	42		48	45	65.4	65.6		69.5	69.8
Cascade.....				99	95			41	44	48				68.6	71.4
Chouteau.....				98	94				34	38				65.3	66.4
August:															
Augusta.....	86	92	91	89	93	35	32	31	31	31	61.1	60.3	60.8	62.9	60.2
Great Falls...	89	94	86	93	96	43	42	17	42	44	67.0	65.5	53.6	70.2	65.4
Cascade.....			100	96	94			35	40	38			67.4	70.2	63.4
Chouteau.....				95	97				35	39				65.6	62.5
September:															
Augusta.....	83	80	88	85		23	20	19	27		49.9	50.6	55.6	55.1	
Great Falls...	83	80	90	86		28	30	30	32		56.7	56.1	57.8	58.6	
Cascade.....			96					26					60.4		
Chouteau.....				87					27					57.2	
October:															
Augusta.....	80	80	81	78		19	20	11	-2		45.8	48.8	47.8	40.6	
Great Falls...	77	78	80	77		22	25	28	2		48.8	51.8	50.6	41.0	
Cascade.....			86	85				22	3				48.4	45.0	
Chouteau.....				78					-4					40.6	
November:															
Augusta.....	54	72	74	74		-2	-39	10	-28		28.9	27.0	43.0	35	
Great Falls...	58	70	65	64		6	-25	17	-18		32.6	31.6	45.8	36.7	
Cascade.....			66	69				13	-21				47.6		
Chouteau.....				75					-24					37.1	
December:															
Augusta.....	52	61	60	56		-17	-14	-26	-10		24.2	33.0	29.7	32	
Great Falls...	52	56	54	51		-10	-12	-20	-16		23.6	33.8	31.4	31.4	
Cascade.....			67					-24					33.3		
Chouteau.....				58					-9					33.0	

RAINFALL.

There is only a moderate amount of rainfall throughout the Great Falls region, especially in that portion bordering the adjacent mountain ranges. On the lower lands farther out on the plains more arid conditions prevail. A characteristic of the annual precipitation in this region, as in other parts of Montana, is that a large percentage falls during the growing season. The amount of rainfall received during the four summer months nearly equals that for the remainder

of the year—a feature peculiarly favorable for agriculture. The mean monthly precipitation at Great Falls for a period of ten years, 1893 to 1903, inclusive, is as follows:

Mean monthly precipitation at Great Falls, Mont.

January	0.6	July	1.6
February	.5	August	.6
March	.7	September	1.1
April	1.2	October	.4
May	2.6	November	.8
June	2.8	December	.5

During the period of ten years above described the total rainfall for the driest year was 6.7 inches, while the total for the wettest year was 17.3 inches. The average depth of snow for this period is 39.6 inches, and the heaviest snowfall in twenty-four hours is 9.3 inches.*

In order to show the relative precipitation of the regions adjacent to the mountains and those farther out on the plains, the following comparative table is introduced:

Relative precipitation at Augusta, Great Falls, Cascade, and Chouteau for five years (1902-1906, inclusive).

	Rain and snow (melted).					Snow.				
	1902.	1903.	1904.	1905.	1906.	1902.	1903.	1904.	1905.	1906.
January:										
Augusta	0.14	0.19	0.21	0.40	0.51	3.3	1.5	2.5	4.0	5.0
Great Falls	.16	.08	.17	.32	.32	1.6	.7	1.7		
Cascade				.23	.20				4.5	7.1
Chouteau					.12					
February:										
Augusta	.49	.18	.15	.40	.45	8.2	2.0	1.0	4.0	4.5
Great Falls	1.02	.35	.51	.17	.77	9.8	3.5	4.9		
Cascade				.31	.85				9.0	10.0
Chouteau				.12	.08				2.4	Tr.
March:										
Augusta	.76	1.00	2.18	2.27	.70	14.0	10.0	18.0	1.5	7.0
Great Falls	.19	.89	2.20	.68	.73	1.6	8.0	22.0		
Cascade				.55	.63				8.5	9.1
Chouteau				.56	.31				4.6	
April:										
Augusta	.35	1.71	.50	1.78	.92		13.0	1.5	10.0	
Great Falls	.05	2.00	.62	.68	1.17			Tr.		Tr.
Cascade				.84	1.16				11.5	
Chouteau				.55	.56					
May:										
Augusta	4.16	2.48	.92	1.52	6.43	2.5	8.0	6.0		
Great Falls	5.93	1.84	1.16	1.99	5.03				Tr.	
Cascade				2.30	5.79				Tr.	.1
Chouteau				1.45	4.47				2.0	
June:										
Augusta	.79	1.36	.99	4.97	.97					
Great Falls	4.02	2.19	1.06	4.23	5.59					
Cascade				5.48	2.69					
Chouteau				2.63	1.57					
July:										
Augusta		3.54		1.70	1.00					
Great Falls	2.14	2.74	.97	.67	.88					
Cascade			.29	1.04	.80					
Chouteau				1.25	1.14					
August:										
Augusta	.77	1.51	.32	1.44	2.18					
Great Falls	.55	.74	1.18	.82	2.66					
Cascade			.12	2.05	3.15					
Chouteau				.70	2.75					

* A portion of the data above and in the statements immediately following are for the period from 1893 to 1903. The remainder is computed from the establishment of the station in 1891.

Relative precipitation at Augusta, Great Falls, Cascade, etc.—Continued.

	Rain and snow (melted.).					Snow.				
	1902.	1903.	1904.	1905.	1906.	1902.	1903.	1904.	1905.	1906.
September:										
Augusta.....	.36	.75	.16	.07						
Great Falls.....	.74	.99	.14	.18			Tr.			
Cascade.....			.13							
Chouteau.....				.27						
October:										
Augusta.....	Tr.	.27	.10	.47			2.2	1.0	5.0	
Great Falls.....	.07	.45	.44	.26			Tr.	Tr.		
Cascade.....			.29	.38				Tr.	4.0	
Chouteau.....				.10						
November:										
Augusta.....	.32	1.71	Tr.	.60				16.0	Tr.	6.0
Great Falls.....	.45	.83	.01	1.25				8.3		
Cascade.....			.02	1.50						10.3
Chouteau.....				.26						
December:										
Augusta.....	1.00	.69	.40	.10			6.0	4.0	1.0	
Great Falls.....	.39	.91	.54	.18			9.1	8.0	1.8	
Cascade.....			.38	.20					2.0	
Chouteau.....				Tr.					Tr.	

CULTURE.

Settlement here as elsewhere is determined by geologic and climatic conditions. Along all the larger stream valleys where surface water for irrigation purposes is available settlements are numerous, but much of the upland and grazing districts is thinly populated. On the higher slopes bordering the mountains in the zone of increased rainfall many small farms occur, some of which are among the best improved places found in the district.

One relatively large town, three medium-sized coal-mining towns, and a number of smaller trading points are in the district. Great Falls, a town of 18,000 inhabitants and a thriving business center, is located on Missouri River near the north-central portion of the district. Although at present none of its railroad lines are trans-continental, they are the most important connecting lines between the main lines of the Great Northern and the Northern Pacific, and when the Billings and Northern road, now being constructed between Billings and Great Falls, is completed it will open up a new trans-continental route through Great Falls to the northwest coast. At present railroad lines extend in four directions from Great Falls: The Great Northern southwestward to Helena and Butte; the Montana and Great Northern northwestward to Shelby Junction, a point on the main line of the Great Northern; the Great Northern extending northeastward to Havre, another point on the Great Northern main line; and the Neihart branch of the Great Northern connecting Great Falls with Neihart, a silver-mining town in the Little Belt Mountains about 100 miles to the southeast. This road has a short branch line leaving it at Gerber station for Stockett and Sand Coulee, two of the larger coal-mining camps. The Boston and Montana Consolidated Copper and Silver Mining Company's smelters and

refineries are located at Great Falls; also the Royal Milling Company, besides a number of smaller business enterprises. The ore handled at the smelters comes from Butte and Anaconda; this, together with the coal and limestone used in the operation of the plant, makes a relatively large freight traffic for Great Falls, while it also furnishes employment for a large force of men.

Belt, one of the largest coal-mining towns in the region, has a population of about 1,000, composed mainly of employees of the Anaconda Copper Mining Company, the largest operators at this place. It is located on Belt Creek, about 20 miles southeast of Great Falls, on the Neihart branch of the Great Northern road, and is the oldest coal-mining town in this region. About 10 miles west of Belt and about 10 miles from Great Falls are the two coal-mining towns of Stockett and Sand Coulee. At Stockett, the larger of the two places, is located the Cottonwood Coal Company, which is one of the two largest coal-mining companies operating in the district. Stockett has a population of about 800, composed largely of coal miners employed by the Cottonwood Coal Company. Sand Coulee, about $2\frac{1}{2}$ miles northwest of Stockett, is a smaller mining town of about 400 inhabitants. It is situated in Straight Coulee, a branch of Sand Coulee, and owes its existence mainly to the Nelson and Gerber coal companies, which are operating at this place.

The other towns in the district are mainly supported by a ranch population. Chouteau, the most important of these and the county seat of Teton County, is located on Teton River, about 40 miles northwest of Great Falls. It has a population of about 400, and is bordered on the north by one of the oldest and best-developed irrigated districts in the Great Falls region. Along Sun River there are a number of small towns and trading points. The largest of these is Augusta, in Lewis and Clark County, on South Fork of Sun River, about 3 miles above its mouth. Sun River, somewhat smaller, although one of the oldest towns in this region, is located in Sun River Valley, about 20 miles west of Great Falls. Two towns have recently been laid out in Sun River valley by the Reclamation Service engineers—one at Fort Shaw Indian School, which will be known as Shaw, and another at the mouth of Sims Creek, which is called Sims. At Flowerree home ranch there is a large company store and another at Sunnyside, owned by the Sun River Stock and Land Company. Along the Great Northern Railway line the principal town within the area described is Collins, located on the north side of Teton River. From this place stage lines connect with Chouteau through Farmington, a post-office and store in the middle of Burton Bench. Bynum, another small trading point, is located in the northwest part of Burton Bench.

There are no towns along Missouri River below Great Falls within the area described, but above that town are two small stations, Ulm and Cascade, the latter, located near the base of the Big Belt Mountains, with a population of about 200. It is supported by a large ranch trade from each side of the river.

On Smith River there is a post-office known as Truly, about 5 miles above its mouth; another, Orr, farther up the river, has recently been discontinued.

In Belt Creek valley, about 2 miles above Belt, is the small town of Armington, which is situated at the junction of the new Billings and Northern and the Neihart branch of the Great Northern. It is mainly a small railroad town, which receives a portion of the ranch trade of the surrounding country. Along the new railroad there are a few small stores, located at intervals of 12 to 15 miles; these are Spion Kop, Geyser, and Stanford, the latter being an important trading point for a large ranch district along Skull, Running Wolf, and Sage Creek valleys.

While the Great Falls region is at present a sparsely settled district, it is believed that the Government irrigation projects now under way which will reclaim millions of acres of fertile farming land, the almost unparalleled advantages for the development of water power, and the increasing railroad facilities will cause the population to increase rapidly within the next decade.

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1908

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, DIRECTOR

WATER-SUPPLY PAPER 222

PRELIMINARY REPORT
ON THE
GROUND WATERS OF SAN JOAQUIN
VALLEY, CALIFORNIA

BY
WALTER C. MENDENHALL



WASHINGTON
GOVERNMENT PRINTING OFFICE
1908

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PRELIMINARY REPORT ON THE GROUND WATERS OF THE SAN JOAQUIN VALLEY.

By W. C. MENDENHALL.

INTRODUCTION.

The agricultural situation in that part of the United States known as the Southwest is peculiar in that within it consumption tends constantly to exceed production. This is due to the large areas of desert, unsuited for agriculture but supporting many other industries. The entire irrigated acreage in the 11 arid States lying for the most part west of the crest of the Rocky Mountains was 7,539,545 acres at the time the Twelfth Census was taken in 1889. Since that date the irrigated acreage has been greatly expanded, and through the operation of the reclamation law and the impulse given by it to private enterprise that expansion will continue; but the population also has grown, and this growth in the future will be even more rapid than it has been in the past.

In the States of Nevada, Arizona, and New Mexico the mining industry becomes yearly of greater importance, and the influx of people engaged in it is increasing correspondingly. The growth of trade with oriental countries and the development of the mineral resources of Alaska have resulted in great accessions to the population of Pacific coast-seaports, particularly those about San Francisco Bay and Puget Sound, and in greatly increased demands for food products. Southern California, as that portion of the State lying south of the Tehachapi Mountains is called, is receiving rapid recognition as a playground for the people of the entire United States, and of the thousands of tourists who visit this area each year many become permanent residents.

Of the areas in the Southwest within which food products for its cities, its tourist centers, and its mining regions must be raised, the largest and most promising is the interior lowland known as the Great Central Valley of California. The southern segment of this lowland,

the San Joaquin Valley, contains 7,360,000 acres, of which but 750,000 were under irrigation in 1899, and probably not more than 1,125,000 acres are irrigated at present. Southern California contains a million acres of land that would be cultivable if water were applied to it; yet in this region, where all the water resources are utilized, but 225,000 acres are under irrigation, and the remaining area is non-productive or yields only a small and uncertain crop through dry-farming methods.

Furthermore, the density of population in the irrigated valleys south of the Tehachapi means the consumption there of practically all the staple food products raised. Fruits, especially the citrus varieties, are grown for export, and in some years more grain is produced than is necessary for local needs; but in general the demand in this area for food staples is in excess of the local supply.

The Imperial Valley, in southeastern California, promises to become a very productive area through the utilization of Colorado River water, and many other sections might be mentioned whose acreage will increase the total area under irrigation, but all of them together are smaller than San Joaquin Valley, which, with that of the Sacramento, must become the chief agricultural district of the Southwest.

The agricultural development of this valley is controlled by the distribution of rainfall, the character of the soils, and the possibility of applying other water than that which reaches the valley as a direct result of precipitation upon its surface. Its extreme southern end, in the vicinity of Bakersfield, is strictly arid, the average rainfall there being less than 5 inches. Precipitation increases gradually toward the north, until at Red Bluff, in the northern end of Sacramento Valley, the annual rainfall averages 25.7 inches. Intermediate areas receive an amount of precipitation intermediate between these two extremes; but south of San Francisco Bay the available records indicate a rainfall of less than 16 inches, and over the greater part of this area of less than 12 inches—an amount that is insufficient to insure crops, even of grain, and is entirely inadequate for the other diverse food crops which a dense population demands.

The progressive increase in aridity from the northern toward the southern end of the valley trough prevails to an equally marked extent east of the valley, in the mountain areas from which its surface waters are drawn. The total run-off from the Sierra, according to the best available records, is about 11,500,000 acre-feet annually. Of this amount, 3,000,000 acre-feet are supplied by the streams from Kings River southward and 8,500,000 acre-feet by the streams north of Kings River. The combined drainage area of the streams from Kings River southward is 5,143 square miles; that of the streams north of Kings River is 7,543 square miles. That is, a southern portion of the Sierra, whose area is nearly seven-tenths as large as the

northern portion, yields but one-third as much water in the form of stream discharge. Hence in the south end of San Joaquin Valley the acreage which is irrigable by the use of surface waters is very much less than that in the northern end of the valley, and the area available for development here is correspondingly greater than that available farther north.

The question of water supply is, of course, not the only one that confronts those who desire to see the development of the San Joaquin Valley proceed rapidly, although it is properly regarded as the most pressing. The quality of the soil, particularly with reference to the presence of hardpan or of alkali, is of the utmost importance. Extensive alkaline areas exist along the axis of the valley and part way up its eastern slope, especially at points where the ground waters lie close to the surface, and hardpans of at least two types underlie some of the higher and otherwise most valuable lands. These soil problems are being studied systematically by the soil experts of the Department of Agriculture^a and the reports that are issued should be supplemented as rapidly as possible, until definite information as to soils is available for the entire valley.

CONDITIONS LEADING TO THE PRESENT INVESTIGATION.

The conditions already outlined—namely, the great actual and the much greater prospective importance of the San Joaquin Valley as an agriculturally productive center—have led during the last decade to greatly increased interest in the possibility of adding to the acreage under irrigation, and hence to the output in food products.

Irrigation enterprises, like those of other industries, invariably pass through a pioneer stage, in which only the most easily accessible resources are utilized. In this stage the methods of application of water are wasteful, the land holdings are large, and the agricultural output is low. Only later, when the population becomes much more dense and the need of greater output is clearly recognized, do methods so improve that the ratio of output to area, to resources, and to investment becomes such as to satisfy economic demands.

In Southern California irrigation methods have been carried to a greater degree of refinement than in any other section of the United States. When irrigation began here, during the first third of the nineteenth century, short, crude ditches were constructed by which the waters utilized were diverted from the lower courses of the streams to near-by lands upon which they were turned, and the only products were grain and pasture, by which the flocks and herds were

^a Lapham, Macy H., and Helleman, W. H., Soil survey of the Hanford area, Cal.: Full operations of the Bureau of Soils for 1901, U. S. Dept. Agr. The results of similar surveys are available for areas about Bakersfield, Fresno, and Stockton.

carried through the dry season. Such methods were in vogue until the late sixties and early seventies, when American settlers entered the country and attempted to utilize lands that had been regarded as entirely worthless. These settlers brought with them capital, and constructed their ditches on higher lines and in a much better manner than did the old Spanish *zanjas*. They applied water much less lavishly, to larger areas, and with much better unit results, and so by continued improvements of this type all of the surface waters were finally utilized to the best advantage. But settlers continued to flock to the region, and attention was then turned to the underground waters, which were developed at first only to supplement the surface supplies. Such reservoir sites as were available were also filed upon and made use of, and eventually many enterprises were started, some of which depended on a combination of surface and underground waters, and others on underground waters alone. Still later refinements resulted in the reconstruction of many of the old ditches, the replacement of open canals by underground pipes, and the elimination thereby of waste by seepage and evaporation. In the lower lands wells were drilled which yielded flowing water, and stream waters which had previously been utilized on these lower lands were diverted to the bench lands, where products of higher value could be grown.

As a result of this intensity of development it is probable that in no area in the United States are the waters so thoroughly utilized as in the region that lies south of the Tehachapi Mountains. In their passage from the mountains, where they originate in precipitation, to the sea, where they are lost, some portions of these waters are used as many as eight times—in power plants, in irrigation from surface streams, and finally by the recovery of that portion of the surface flow which, sinking in the alluvial fans, augments the supply in the underground reservoirs.

Much of the San Joaquin Valley is still in the pioneer stage of irrigation development, depending almost exclusively on surface waters, and in a large part of the area waste is great, over-use is the rule, and, as a consequence, minimum production results from a maximum use of water. But the pioneer stage is passing. Engineers trained in more refined methods are entering the region and applying their training. Special communities, like those about Portersville and Lindsay, where citrus fruits are raised, have for a decade or more used deep underground waters, whose cost greatly exceeds that of surface waters where the latter are available in other parts of the valley. This relatively high cost is amply justified, however, in the citrus belt by the great value of the products.

In other parts of the valley, as, for example, in the neighborhood of Corcoran, capitalists who had profited in other regions through the use of flowing artesian waters have undertaken to develop colonies by

utilizing waters of this type, whose existence had been proved years before by the owners of large cattle ranches, who had put down wells to obtain water for stock.

In still other districts, as about Bakersfield, Stockton, and Fresno, isolated individual pumping plants have been installed within the last decade, and by their use lands whose owners had been unable to secure rights to the limited supply of surface waters have been brought within the productive zone.

These more or less isolated experiments and their successful outcome have resulted in a widespread recognition of the fact that the productivity of the San Joaquin Valley can be greatly increased by the utilization of the heretofore neglected ground-water resources. This recognition has been followed logically by a desire for specific information as to the quality, occurrence, accessibility, character, and proper use of waters of this type. In response to this demand the Reclamation Service, in 1905, before its separation from the Geological Survey and erection into a separate Bureau of the Department of the Interior, determined to investigate the ground waters of the valley, with the hope that it might become possible to establish there a reclamation project whose water supply should be obtained from the underground reservoirs. Similar investigations were conducted in other parts of the United States during the first three or four years after the passage of the reclamation act, and as a result of these investigations the energies of the Service were concentrated upon those projects which it found most practicable.

The San Joaquin Valley did not afford one of these most practicable projects, and the investigations begun there by the Service were terminated; but the work already carried out had given some idea of the wide extent, the easy accessibility, and the high quality of the underground waters in many parts of the valley, and the Geological Survey decided to continue the work begun by the Reclamation Service. As the appropriations available for this work have not been sufficient to permit it to be carried through in a continuous and systematic manner, its progress has been greatly interrupted, and there has been much delay in the preparation of results.

In the spring of 1905 A. J. Fiske, R. M. Priest, and S. M. Smith were assigned to work in the valley and spent about two months preceding the 1st of July in the collection of preliminary data. The work was resumed in the spring of 1906 by W. N. White and H. R. Boynton, jr., and was continued during the summer of 1907 by Mr. White, who, before the close of the year, had completed the collection of data on the flowing wells, pumping plants, and on many of the domestic wells throughout the valley. During about the same periods H. R. Johnson had been assigned to carry out a geologic study about the borders of the valley, in order to determine its structures,

in so far as they might bear upon the occurrence of the ground waters of the valley proper.

Much remains to be done in order that satisfactory data may be procured on all phases of the ground-water problems in the great area and reliable conclusions reached from the study of these data. More definite knowledge is needed as to the cost of developing ground waters under all conditions; the distribution of the alkaline waters that can not be used safely either for drinking purposes or for irrigation is not known with sufficient definiteness; and estimates are needed as to the costs of placing San Joaquin River waters on the arid west-side lands that would be so highly productive could they be irrigated. Nevertheless it seems advisable to issue a preliminary report at this time in order to make available such facts as have been gathered and to call attention to the ground waters as a resource whose more general use will probably be the largest single element in the future development of the valley. Especially will the installation of small pumping plants by individual landowners, who will thereby control their own water supplies, prove of great importance in the future.

A single small-scale map (Pl. I) accompanies this report. In its preparation, the topographical and engineering map of the San Joaquin Valley issued by the California State engineering department in 1886 was used as a base. Some slight additions and corrections have been made as a result of later surveys, but the earlier map has been used substantially in its original form. Upon this base the area in which flowing wells may be obtained has been outlined with as much accuracy as the information at hand permits. Beyond the limits of the artesian area the attitude of the ground-water plane has been indicated by hydrographic contours, which are based on the elevations of the surface as indicated by the topographic sketch contours of the base map. Neither set of contours is accurate in detail, but it is believed that the relations between the two—that is, the depths to ground water at various points—are correct within a reasonable margin of error, so that the map will be of practical value. It must be remembered, in using this map, that ground-water levels do not everywhere remain constant. On the deltas and in the irrigated areas there is a more or less regular annual variation in level, the plane of saturation rising during the high-water period—the period of maximum irrigation in early summer—and falling during the low-water period in the autumn and early winter. In the past there has been a marked permanent rise in the ground-water level in areas to which water has been applied by the construction of the large canals of the greater irrigation systems. This rise still continues in some localities, to which water has been applied for a number of years, and it will be marked in regions to which canal systems may be extended in the

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future, although the chief changes of this character have doubtless already been brought about. In one or two limited areas there is probably also a general decline in ground-water levels. It is not possible, of course, to indicate a varying water level by a single set of hydrographic contours. Those used indicate about the position and form of the water plane in the period from 1905 to 1907.

GEOGRAPHY OF THE VALLEY.

San Joaquin Valley and Sacramento Valley together constitute the Great Central Valley of California, with an area of nearly 16,000 square miles. This level-floored depression is more than 500 miles long and varies from 20 to 50 miles in width. East of it the Sierra rises to between 14,000 and 15,000 feet above sea level, and west of it the lower coast ranges separate it from the Pacific. The greatest elevation of the Sierra is near its eastern edge and all its important drainage is westward toward the Great Valley, an important fact upon which the greater part of the actual and prospective agricultural value of the valley depends. The coast ranges are a series of parallel ridges of moderate elevation that inclose valleys, like those of the Salinas and Santa Clara, which, when not too arid, are highly productive.

The Great Valley itself exhibits little diversity in its physical aspect. Such differences as exist between its north and south ends are climatic, or, if physical, are directly due to climatic differences. Among local physical features based upon climatic differences may be mentioned the Tulare basin at the south end of the San Joaquin Valley, due to the aridity of the region and the consequent extensive development of alluvial fans. Two of these, extending from Kings River on the east and Los Gatos Creek on the west side of the valley, have coalesced in a low ridge south of which lie the Tulare Lake and Kern Lake depressions. Basins different in character and situation, but originating nevertheless in climatic conditions, are the overflow basins of the Sacramento and the lower San Joaquin valleys, of which the Yolo basin may be mentioned as a type. These basins occupy the lowest portions of the flood plains just outside the ridges that form the immediate river banks.

The central valley opens to San Francisco Bay and thence to the Pacific through Carquinez Straits and the Golden Gate, and the combined drainages of the Sacramento and San Joaquin systems discharge through these gateways. Other passes, like the Tehachapi, the Tejon, and Walker Pass near the south end of San Joaquin Valley, and the Livermore Valley gateway near Carquinez Straits, exist through the mountain barriers that surround the central lowland, but they are not as low nor as pronounced as the central tidal gateway. In general it may be said that the Great Valley is completely inclosed except for this opening.

The larger lobe of the central depression, extending southward from Cosumnes River and Suisun Bay, is generally known as San Joaquin Valley, although it is not all drained directly by San Joaquin River and its tributaries. The southern more arid third of the depression, extending from Kings River delta to the Tehachapi Mountains, has no surface outlet under normal conditions, and the surface waters accumulate in the Tulare Lake depression and the Buena Vista reservoir. Originally Kern Lake received a portion of the excess from Kern River, but through the protection afforded by a restraining dike water is kept out of it except as unusual floods may break the restraining dam, and the original lake bottoms have become valuable wheat lands.

The streams that drain into the valley from the Sierra carry practically all of the water that reaches it. They are in every way more important than those that enter it from the west. They have larger drainage basins, individually and collectively; they have longer courses; and they flow from higher mountains, with a much greater rainfall and a better protective covering of forest and brush; hence their discharge is many times greater and much less erratic than that of the west-side streams.

The total drainage area^a tributary to the valley from the Sierra is 16,089 square miles; from the Tehachapi and Coast ranges 4,293 square miles, and the area of the valley floor is 11,513 square miles. The total area of the San Joaquin basin is therefore 31,895 square miles.

The average run-off of the principal east-side streams north of Kings River, with a combined drainage area of 7,543 square miles, is about 8,500,000 acre-feet, while that of Kings, Kaweah, Tule, and Kern rivers, discharging into the Tulare basin from a watershed with an area of 5,143 square miles, is about 3,000,000 acre-feet. The total discharge into the valley from 12,686 square miles of Sierra watershed is therefore about 11,500,000 acre-feet.

The preponderance of east-side streams has given the valley floor its well-marked unsymmetrical form. The valley axis, the line of lowest depression, is throughout much nearer the western than the eastern foothills. In places it lies against these hills, but elsewhere, as between Los Gatos and Cantua creeks, the west-side slopes are 15 or 18 miles wide, at least one-half as wide as those of the east side. They are also steeper than those of the east. Grades of 20 or even 40 feet to the mile are not rare, and it is unusual for the grades to be less than 6 or 8 feet per mile. On the east side 30 feet to a mile is about the maximum gradient, while 5 feet or less is perhaps the average.

^a Hall, William Ham., *Physical data and statistics of California*, pp. 396 et seq.

These conditions are due directly to the fact that the valley floor has been built up by the alluvial material eroded by the streams from the mountains east and west of the depression and deposited in it. The larger and more active streams build flatter but more extensive alluvial fans--the type that makes up the east-side slopes; the more erratic and torrential streams of smaller volume build the steeper and less extensive fans that constitute the west-side slopes.

GEOLOGIC OUTLINE.^a

THE ROCKS OF THE VALLEY BORDERS.

In simplest outline, the geology of the eastern border of San Joaquin Valley consists of the "Bedrock series" of granites and metamorphic sedimentary and igneous masses of pre-Cretaceous age, overlain at the north and south ends of the valley in an interrupted band occupying a zone of low relief between the Sierra proper and the valley proper by a series of Tertiary sediments, entirely unaltered and including beds as old as the Eocene, although the great body of the material seems to be Miocene or Pliocene in age. Between San Joaquin River and Portersville this zone of late sediments is missing, and the sands and gravels of the valley proper lie upon the flanks of the Sierran granite and metamorphic complex. Because of this hiatus the east-side Tertiary is separated into two bodies, of which the northern extends from Fresno River nearly to the Cosumnes, and the southern, conveniently designated as the Bakersfield area, extends from Deer Creek to the Cañada de las Uvas.

The northern area of Tertiary rocks, which is chiefly in the Milton-Merced regions, includes a lower, clayey series that has been called the Ione formation, a middle zone of andesitic sandstone, coarse volcanic breccias, and tuffaceous beds, and an upper gravelly series that is in places auriferous. This upper series usually occurs along the most westerly foothills and merges at many points with the gravels and soils of the valley floor.

The southern area consists of alternating beds of soft sandstone, clay, and gravel, the uppermost beds being coarse, like those of the northern area, and scarcely distinguishable in some places from the alluvium of the valley itself.

The geology of the western margin of the valley contrasts in many ways with that of the eastern border. The oldest rocks of the Mount Diablo Range--the easternmost of the coast ranges--comprise a series of altered igneous and sedimentary rocks known as the Franciscan series, which extend along the axis of the range from a point southwest of Coalinga to San Francisco Bay. Overlying them

^a Abstract from a manuscript by H. R. Johnson, on the geology of the borders of the San Joaquin Valley.

on the valley side, but not continuously, is a series of sandstones, shales, and conglomerates of Cretaceous and oldest Tertiary age. Succeeding these in turn is a variable series, locally of great thickness and usually but not always present in some of its members, representing the Neocene—that is, the middle and upper Tertiary. These rocks, like the older sediments beneath them, are sandstones, shales, and conglomerates, but usually they are less firmly indurated than the Eocene and Cretaceous rocks. They overlie the latter unconformably and contain many unconformities within themselves, with a resulting variability in thickness and irregularity in extent of individual beds. This series contains the siliceous shales generally spoken of in literature as the "Monterey," besides a great variety and abundance of sandstones and conglomerates. Toward the top of the series are beds that clearly represent fresh water or subaerial deposition, undoubtedly much like that which is now taking place in Tulare lake and in the west-side alluvial fans. As a whole the sedimentary series dips toward the valley, although interruptions like the anticline of the Kettleman and McKittrick hills in places vary the prevailing monoclinal dips. In general the structures of the valley border are more complex at the south end than along the middle portion and at the north.

The valley as a whole is a great structural trough and appears to have been such a basin since well back in Tertiary time. Since it assumed its general troughlike form, gradual subsidence, perhaps interrupted by periods of uplift, has continued and has been accompanied by deposition alternating at least along what is now its western border with intervals of erosion. This interrupted but on the whole continuous deposition seems to have been marine during the early and middle Tertiary; but during the later Tertiary and Pleistocene, when presumably the valley had been at least roughly outlined by the growth of the coast ranges, fresh-water and terrestrial conditions became more and more predominant, until the relations of land and sea, of rivers and lakes, of coast line and interior, of mountain and valley, as they exist now, were gradually evolved. As these conditions developed, the ancestors of the present rivers probably brought to the salt and fresh water bodies that occupied the present site of the valley and its borders, or, in the latest phases of the development, to the land surface itself, the clays, sands, gravels, and alluvium that subsequently consolidated into the shales, sandstones, and conglomerates of the late Tertiary and Pleistocene series, just as the present rivers are supplying the alluvium that is even now accumulating over the valley floor.

The very latest of these accumulations are the sand and silt and gravel beds penetrated by the driller in his explorations for water throughout the valley. They are like the early folded sandstones,

shales, and conglomerates exposed along the flanks of the valley, except that they are generally finer, are not yet consolidated or disturbed. The greater part, perhaps all of them, accumulated as stream wash on the valley surface or in interior lakes like the present Tulare Lake, but a proportion of the older sediment that is greater as we delve farther back into the geologic past accumulated in the sea or in salt bays having free connection with the sea. It is these very latest geologic deposits, saturated below the ground-water level by the fresh water supplied chiefly by the Sierran streams, that constitute the reservoirs drawn upon by the wells, whether flowing or pumped, throughout the valley.

The chemical characters of the ground waters, as well as their occurrence and accessibility, are related to geology. If the valley alluvium is derived from the Cretaceous and Tertiary beds of the coast ranges, rich in gypsum and other sulphates and carbonates which are relatively easily soluble, the ground waters that percolate through it will soon dissolve large quantities of the salts. If the alluvium, on the other hand, is derived from the granites and metamorphic rocks of the Sierra, whose potassium, sodium, and calcium compounds are in the form of resistant silicates, the ground waters dissolve out these constituents slowly and under all ordinary conditions remain quite free from salts.

Obviously if the sands and gravels through which the ground waters percolate were deposited under such conditions that salts were deposited with them, as in the salt water of the sea or of bays like San Francisco Bay, or in interior lakes that are saline through evaporation, as is true of Tulare Lake, then the ground waters themselves will quickly become saline, although when they leave the mountains as surface waters, before their absorption by the alluvial fans, they may be as pure natural waters as are known in the world.

ORIGIN OF THE PRESENT VALLEY SURFACE.

The lowland through the heart of California known as the Great Valley, whose origin as a depression appears, in accordance with the facts just outlined, to date well back into Tertiary time, owes its actual surface to more recent action and to more obvious agents. That surface is, in brief, a combination of the surfaces of a great number of alluvial fans, originating at the mouths of the canyons through which the tributary streams discharge from the mountains into the valley.

Each stream that enters the valley brings with it from the mountains a greater or a smaller quantity of sand, gravel, or bowlders. All or a part of this burden is deposited in the valley, and the deposit constitutes the alluvial fan of that particular stream. The apex of each fan is the mouth of the stream canyon. From this apex it

broadens and flattens until it coalesces at its periphery with other fans. The stream that built it usually spreads delta-wise over it, discharging through a number of diverging channels into the trough of the valley. As a rule these spreading distributaries flow upon the surface of the fan, but some of the major streams from the San Joaquin northward are incised into the valley floor in shallow trenches 100 feet or less in depth. This must be due to special conditions, such as recent change in volume of stream flow or in elevation of the land relative to the sea—conditions not yet understood.

The fans of different portions of the valley indicate by their mass and form the conditions of volume and distribution of rainfall under which they originated. The west-side fans, particularly those in the middle of the valley and near its southern end, are steep and symmetrical, forms characteristic of areas of low rainfall very irregularly distributed. The east-side fans are of much greater mass and lower slope because the rivers that built them have a greater flow of somewhat less irregular character. The Kern River fan has grown westward against the McKittrick hills until it has isolated the Buena Vista basin south of it. Before dams had been built, interfering with the natural conditions here, a shallow lake occupied the present site of Buena Vista reservoir and the old bed of Kern Lake, and during seasons of unusual rainfall there was overflow northward toward Tulare Lake. The basin occupied by Tulare Lake is likewise due to the aridity of the valley and the consequent development of the Kings River and Los Gatos Creek fans. South of the low, broad ridge due to the coalescing of these two fans is the Tulare basin, in which a part of the surplus waters of the streams south of it accumulate. As a consequence of the flatness of this basin and the very erratic character of the supply that reaches it, the lake fluctuates widely in area during a series of years.

Northward from Tulare Lake basin the discharge of the streams is sufficiently great and sufficiently constant to prevent the formation of delta-dams like those formed by Kings River and Los Gatos Creek fans, and an open channel is maintained from the San Joaquin northward to Suisun Bay.

Along the lower course of the San Joaquin, conditions resemble those in the Sacramento Valley, i. e., they are the conditions usual along rivers draining humid rather than arid regions. Large areas are subject to regular annual inundation during the spring floods or are protected from this inundation only by the construction of artificial levees. The greater part of the water that inundates this area is supplied by the Sacramento system, but the greatest overflow occurs when the floods appear in the two systems at the same time.

The essential fact as to the present valley surface is that it is a direct result of stream action. It has everywhere been built up by deposition from the streams or from the fluctuating lakes that are

themselves dependent upon the streams; and it is formed of materials brought by the streams from the mountainous portions of their drainage basins where they are eroding instead of depositing. Throughout the south end of the valley its surface is a combination of alluvial fan surfaces; at the north end of the valley these fans, less strikingly and typically developed because of the greater precipitation there, still predominate along the valley borders, while the center of the valley is a flood plain of the usual type.

SOILS.

As the valley surface has been molded by stream action into its present form, so the soils of the valley represent deposition by the rivers of materials washed out of the mountains from which they drain. This soil is modified in various ways after the streams have deposited it—by disintegration of the rock particles where the streams have left them, by the mingling of the products of vegetal decay where vegetation is abundant, or by chemical processes in place, such as the formation of hardpans or the accumulation of alkalis; but the soil foundation, so to speak, reflects pretty closely the type of rock outcropping in the drainage basin of the stream on whose delta the particular soils are found.

For example, the soils of the deltas of Kern and Kings rivers are in large part of granitic derivation, because granitic rocks form the greater part of the mountain drainage basin of each of these rivers. Their coarseness and the distribution of the coarse and fine phases are to a certain extent matters of accident, due to the location of present or past channels of the streams across their deltas; but in steep alluvial fans the coarser and more bouldery soils occur nearer the mountains. In the fans of those east-side streams from the Merced northward, whose lower courses at least are cut through late Tertiary formations containing a large percentage of lavas and derived products, other types of soil result.

The west-side streams, draining mountains practically free from granites and similar rocks but with soft serpentines, shales, and sandstones, deposit fragments of those rocks in their alluvial fans, and the result is a soil type entirely different from that of the east side and south end of the valley. These shale, clay, serpentine, and sandstone fragments disintegrate much more quickly than the granitic sands that contain large proportions of such resistant minerals as quartz and feldspar, and the result is the mellow, loamy soil with its fragments of siliceous shale that makes much of the west slope of the valley and is so productive whenever water can be applied to it.

Soil of another general class occurs at a few localities along the east side of the valley. This soil is not of alluvial fan origin, brought into the valley by the streams from the surrounding mountains, but is due to decay in place of the rocks underlying the particular area

where it occurs. Soils of this class are found northeast of Fresno beyond Clovis, and in some of the coves like Clark Valley north of Reedley, and perhaps in other foothill valleys in the Portersville-Lindsay district. Some of the rolling wheat lands found in a zone along the eastern border of Stanislaus and Merced counties may also be regarded as derived from the decay of rock in place rather than from inwashed alluvial fan material, but as the rock is itself a late Tertiary sediment differing but little from the alluvial fan material of the same area, the classification of the soils as residual rather than colluvial has no practical significance.

Another type of soil is neither more nor less than fine beach sand. This type is best developed in a zone surrounding Tulare Lake, and it represents the shore lines of that water body when it contained much more water than at present. In places this sand has been reworked by the wind—blown into inconspicuous dunes, as in the "Sand Ridge" near the Kings-Kern county line.

Finally, there are the soils of the "Tule lands" and the "Islands," the areas subject to overflow particularly along the lower course of the San Joaquin and its tributaries, but present, although less extensively developed, in other areas. These lands are black loams or adobes or impure peats, and are very fertile when reclaimed.

The Bureau of Soils of the Department of Agriculture has made detailed surveys of certain areas in the San Joaquin Valley as the beginning of a general soil mapping of the entire valley. The sheets at present available cover areas about Stockton, Fresno, Hanford, and Bakersfield, and others are in preparation. In the text of the reports and in the maps that accompany them, the soils are classified in great detail on a physical basis, and by a proper study of this classification the geologic origin of most of the soils may be traced.

Another task undertaken by the Bureau of Soils, of even greater immediate value, is the mapping of the alkalies. This work is designed to afford suggestions as to the management and reclamation of alkaline soils and prevention of the rise of the alkalies. When it has been completed for the entire valley it will be of great service in preventing sales of worthless lands to purchasers who buy in good faith with the idea of establishing homes. Many sales of this kind have been made in the valley, and any work that will tend to reduce their number is to be welcomed.

SURFACE WATERS.

The streams of the San Joaquin Valley and their characteristics have been referred to incidentally in the preceding pages. These characteristics depend upon the physical geography of south-central California and the control which it exerts over climate. All of the perennial and important streams flow from the Sierra.

Precipitation within the Sierra district depends upon altitude, latitude, and longitude. Up to a certain limit precipitation increases with increase of altitude; beyond that limit, which at the crossing of the Central Pacific is at Cisco, 6,000 feet above sea and 1,000 feet below the summit, precipitation decreases. Rainfall decreases also southward along the summit of the Sierra as well as in the valleys; and in those parts of the range, principally its southern portion, where altitude does not increase regularly from the western toward the eastern margin, so that the effect of longitude is not obscured by that of altitude, vegetation indicates less rainfall as the desert border of the range is approached.

Under these conditions, therefore, it is evident that the greatest discharge per unit of area will come from those streams with the greater proportion of their drainage basins farthest north in the high part of the Sierra but west of the summit.

From the tables of discharge for 1906, as published by the United States Geological Survey, in Water-Supply Paper 213, the following stream run-off in second-feet per square mile is taken:

Run-off of California rivers in second-feet per square mile.

Feather River	2. 72
Yuba River	4. 37
American River	4. 29
Stanislaus River.....	3. 63
Tuolumne River.....	3. 33
Kings River.....	3. 09
Kaweah River	2. 93
Kern River.....	1. 11

Data for the San Joaquin are not available. All these streams except Feather and Kern rivers occupy comparable positions on the western slope of the Sierra and drain the areas of maximum precipitation for their respective latitudes. The rather regular decrease southward from the Yuba to the Kaweah may therefore be assigned with confidence to the effect of latitude on precipitation. The drainage basins of both the Feather and the Kern extend into the very eastern part of the Sierra beyond the zone of maximum precipitation, and the inferiority of run-off from their basins as compared with that of neighboring streams may be assigned, in part at least, to the effect of longitude; i. e., their basins extend so far east as to be measurably affected by desert conditions. Altitude may also be a factor, since each of these streams drains portions of the range which are not so high as areas in the intermediate basins. The discharge of the principal east-side streams and the areas drained by each are summarized in the following table, compiled from the records of the State engineering department of California and from those of the United States Geological Survey.

The number of years of observations from which the average discharge was determined is also given. As several of these records are as short as five years, and one, that of the Kern, as long as seventeen years, it is obvious that they differ in value; but on the whole they supply a concrete indication of the average amount of water discharged into the San Joaquin Valley annually by its chief streams.

Discharge of streams from east side of San Joaquin Valley.

River.	Length of record.	Area of drainage basin.	Average annual discharge.
	Years.	Sq. miles.	Acre-feet.
Cosumnes.....	5	580	582,417
Jackson Creek.....	5	283	101,672
Mokelumne.....	8	657	1,640,057
Calaveras.....	5	491	339,306
Stanislaus.....	11	1,051	1,254,151
Tuolumne.....	11	1,500	1,011,452
Merced.....	10	1,076	1,113,754
Chowchilla.....	5	268	61,834
San Joaquin.....	12	1,637	1,972,145
Kings.....	16	1,742	1,790,187
Kaweah.....	6	619	401,954
Tule.....	9	437	199,444
Kern.....	17	2,345	670,611
Total.....		12,686	11,498,984

The high-water period of the Sierra streams comes during the late spring and early summer months, when the snow accumulated in the winter is melting most rapidly from the mountains; the low-water flow comes during the late summer and fall months after the snows are gone and before the winter rains have begun. These characteristics are illustrated in the following table of monthly discharge of Kings River for 1906, as determined by the United States Geological Survey:^a

Monthly discharge of Kings River, 1906.

Month.	Discharge in second-feet.			Total in acre-feet.
	Maximum.	Minimum.	Mean.	
January.....	25,500	205	2,360	144,000
February.....	2,150	792	1,150	63,900
March.....	21,000	1,220	5,240	322,000
April.....	7,760	2,960	4,720	281,000
May.....	16,900	3,930	10,700	658,000
June.....	26,600	8,320	17,100	1,020,000
July.....	22,400	8,180	16,300	1,000,000
August.....	7,900	1,870	4,300	264,000
September.....	2,020	682	1,120	66,600
October.....	682	385	516	31,700
November.....	610	330	397	23,600
December.....	2,230	330	700	43,000

Each of the major streams discharges from the mountains upon the eastern edge of the valley in a single channel, but after reaching the valley it usually divides into a number of branches, thus spreading over its delta. This characteristic is most marked in the streams that flow into the southern end of the valley, for many of the northern

^a Water Supply Paper 213, p. 159.

tributaries are incised in the valley floor and are thus confined between definite banks. This distribution is much more pronounced during the high-water period of early summer than at other seasons of the year. A main channel of sufficient capacity to carry the low-water flow proves inadequate during the flood period, and there is then overflow into the numerous subsidiary channels.

The natural habit of all of the main streams has of course been extensively modified by irrigation. Canal systems now take from the channels practically all of the low-water flow and an important percentage of the maximum early summer flow. These systems have been described by Grunsky.^a

The west-side streams are practically negligible as factors in the San Joaquin Valley water supply. Only a few of them are perennial, and the late summer flow of these is so slight that a few acres at most can be irrigated by their use. A trifling amount of irrigation of this type is accomplished by utilizing the waters from Los Gatos Creek, Cantua Creek, and others.

UNDERGROUND WATERS.

VALUE FOR IRRIGATION.

Although the underground waters of the valley have been known and used in minor ways practically ever since its settlement, it is nevertheless true that the movement for their extensive utilization as sources of irrigation supply is a late phase of development, for many of the earlier attempts to make use of them resulted in failure.

Among the causes that have contributed to past failures may be mentioned: Application of the developed waters to poor lands, wasteful methods of application; dependence on the continuance of artesian flow; lack of adjustment to the greater cost of pumped waters as compared with that of the gravity waters upon which reliance has heretofore been placed; lack of intensive farming methods and of proper adaptation of crops to soil and locality; too large farm units; and, in a few cases, inadequate transportation facilities.

The most potent of all these causes has been the prevalence of the easy-going methods of the pioneer—the careless, wasteful habits that are a direct inheritance from the grazing and grain-raising period which has not yet passed from the valley. Land and such waters as are utilized have cost little heretofore in the San Joaquin Valley, and things that cost little are lightly valued, no matter what their intrinsic worth. This spirit is fostered by the immense holdings of some of the larger companies. Few of these companies practice intensive cultivation, though their lands are among the best in the valley.

^a Grunsky, C. E., Water Sup. Papers, U. S. Geol. Survey, Nos. 17, 18, and 19. These papers are no longer available for distribution, but they may be consulted in libraries.

Usually hay and grain are raised to feed through the dry season the stock that is in pasture during the grazing period. But although not as a rule intensely cultivated and by no means producing the maximum of food products or supporting the largest possible population, most of the large holdings are more carefully and successfully managed than the quarter section of the small farmer.

Despite all obstacles and discouragements, however, the use of underground waters is gradually extending. Special, high-priced products like the citrus fruits of the Portersville-Lindsay district justify heavy expenditures for production, and underground water has long been successfully used in this section. One of the highest lifts in the world of water for agricultural and horticultural purposes is that of the Badger Irrigation Company's plant at Exeter, with a maximum lift of 586 feet. This is an experiment, but the success of pumping water to great heights to irrigate the specially early citrus fruits of this region is fully demonstrated, the acreage devoted to these products is constantly extending, and the yield is increasing rapidly as groves planted recently approach maturity.

Irrigation by means of pumped underground water is also proving successful under the entirely different conditions that exist about Lathrop, Lodi, and Stockton, in San Joaquin County. About 200 small pumping plants are in operation in this county, the greater number of which have been installed within a few years. By their use alfalfa, vineyards, and varied crops of fruits and vegetables are successfully grown. Windmills also are extensively used, often with auxiliary gas engines attached to the same well. The area in which this type of irrigation is practiced is closely settled, houses are neat, prosperous looking, and well cared for, the villages and cities which supply the country trade and market the products are flourishing, and altogether there is every evidence of successful endeavor and abundant prosperity.

Still other communities whose existence depends upon the utilization of ground waters are the recently established colonies in Kings, Tulare, and Kern counties, of which the Corcoran settlement is a type. This particular locality is within the artesian basin, and a group of deep wells yield flowing waters which are utilized for all purposes. As a result, successful dairy farms have been established, sugar beets are raised, and a factory has been built for the manufacture of sugar from them.

It is thus evident that there is a gradual awakening to the value of the ground waters and their usability, although in many localities the advocate of the use of these waters is still met by the statement that they can not be developed and applied at a profit under agricultural conditions as they now exist. It is true that the pumped waters are

more expensive than the ditch waters, whose cost as a rule is very low. The average cost of the pumped water used by the Kern County Land Company near Bakersfield, with an average lift of 30 feet, is \$1.29 per second-foot for 24 hours on the basis of a charge of 15 cents per horsepower per hour for electric current, whereas the cost of surface water in the same locality is 75 cents per second-foot for twenty-four hours; i. e., the pumped water costs 72 per cent more than the surface water. When it is remembered, however, that almost universally in the San Joaquin Valley water is used in great excess, to the immediate and ultimate injury not only of the lands to which it is applied but of adjacent lands; that on many of the delta lands there is as yet but little intensive cultivation, and that therefore the margin of profit is low; that there is an important proportion of large holdings and absentee ownership dependent upon inefficient hired labor; and above all that, in the midst of the communities in which it is asserted that pumped waters can not be profitably used in agriculture individuals may generally be found who are using them with striking success; when all of these things are taken into consideration, it may be asserted with confidence that the greatest increase in the agricultural development in this valley in the future will be brought about by a utilization of the ground-water supplies, whose development has only begun and whose value is as yet but faintly realized.

It will probably be true in the future, as it has been in the past, that side by side with successful attempts at the utilization of underground waters will be unsuccessful attempts, and that the general movement for full realization upon this asset will be checked here and there by conspicuous failures widely advertised. This is a condition that always arises in any general advance. Each failure should teach its individual lesson as to a particular way *not* to undertake development or to apply water, and should not be interpreted as an argument against the usefulness of the resource under proper conditions, for the fundamental facts remain that ground waters exist beneath the floor of the San Joaquin Valley in immense volume and that over wide areas they are of high quality and very accessible. They are certain, therefore, to be widely used in the future, and by their use hundreds of thousands of acres now arid and unproductive will be brought to yield handsomely.

The development of the ground waters under the conditions that exist at present, when the chief argument against them is their cost as compared with that of the surface waters which have set the standard should follow two or three lines.

In the first place, pumping plants in the higher parts of the delta lands should be used as adjuncts to insufficient gravity supplies. The

supply of the gravity waters during the flood months of May, June, and July is from 2 or 3 to 15 or 20 times that available during the months of August, September, and October, when many crops are maturing. As a consequence many owners of late rights to gravity waters secure a proportion of the flow during the early high-water period, but are left without it during the low-water period, when there is only sufficient to satisfy the earliest rights. Such owners often have enough gravity water for one or two early irrigations, but not more. Under present conditions, therefore, the maturing of late crops is a precarious matter with them, and they are confined practically to those products which will yield returns when irrigated only in the spring or early summer. This is a serious handicap, as it greatly limits the range of their agricultural activity and often condemns their land to idleness during half of the year. By the installation of pumping plants, to be operated only when gravity waters are not available, this handicap is removed, and yet the cost of irrigation is much less than where no surface waters are available and pumps must be operated continuously.

In the second place, in districts that have a market for garden products or for those special farm products whose value and yield justify some expense in their production, as sweet potatoes, celery, asparagus, or onions, the small land owner can well afford to install an individual pumping plant independent of surface supplies. The same method will be successful with crops that require only one or two irrigations a year, as, for example, some of the fancy varieties of grapes that are now raised so profitably in the northern part of the valley.

Another line to be followed in development is the utilization of flowing artesian waters. Along the axis of the valley is a zone with an area of about 4,300 square miles within which flowing waters are available. Over perhaps two-thirds of this area the flowing waters are sufficiently pure to be suitable for use in irrigation.

None of these lines along which it is suggested that ground waters may be used are experiments. Each has been followed successfully in some of the communities in the valley, although in other sections quite as favorably situated the investigator will be told that pumped or flowing waters can not be used profitably. Communities, like individuals, fall into ruts, acquire bad habits, and lose the power of initiative. In this condition they may overlook or fail to utilize some of their most valuable assets.

In the course of this investigation nearly 4,000 wells in the valley have been examined and data collected as to depth, yield, cost, etc. Among them are many flowing wells. For most of the wells the data

are incomplete, but from the records available the following averages have been determined:

Average size, depth, yield, cost, etc., of flowing wells.

County.	Number averaged.	Average diameter. (inches).	Depth (feet).	Yield (miner's inches). ^a	Average cost.	Annual interest on cost at 8 per cent.	Interest charge per miner's inch per year.
Kern.....	10	10	621	53.3	\$1,545	\$123.60	\$2.30
Kings.....	7	9	1,037	30	2,555	204.40	6.81
Tulare.....	32	8	745	26	1,711	136.88	5.26
Fresno.....	7	8	936	20	1,540	123.20	6.16
Merced.....	16	7	350	54	470	37.60	6.84

^a A California miner's inch equals 0.02 second-foot.

These are actual averages based upon the experience of owners of wells already drilled and flowing. They therefore have a definite value as a basis for estimating costs of artesian waters to be obtained as a result of future developments. They may be compared with the charge made on the Kern delta for gravity water, namely, 75 cents per second-foot for 24 hours, equivalent to \$5.47 per miner's inch per annum.

In comment upon the table it is to be said that the Kern County average is too low, because it happens that among the wells for which sufficiently complete data exist for computing these averages there were one or two of exceptionally great yield that have unduly raised the average yield and reduced the cost, thereby giving a figure lower than that which will probably be realized in future development.

It must be remembered further that the figures are based on the assumption that the entire year's flow will be utilized. This assumption can be realized only by the construction of reservoirs in which the water will be stored during the nonirrigating season for use when wanted. Such construction will add to the cost and will reduce the supply in three ways: (1) By a reduction of flow because of the increased height of delivery necessary to discharge into a reservoir; (2) through loss by evaporation from the surface of the reservoir; (3) through loss by seepage from the reservoir.

The uncertainty as to the amount that will be delivered by any artesian well is another disturbing factor in making exact calculations. The area within which flowing waters are procurable has been outlined with approximate accuracy, but the yield of any well can be determined only after the well has been sunk and the necessary capital invested in it. Some of the wells used in computations have delivered much more than the average supply and so have yielded exceptionally cheap waters; others have delivered less than the average, and their waters are correspondingly expensive.

Another condition that must be realized is this: When the number of wells drawing from the artesian supply is greatly increased in any particular neighborhood, the wells interfere and the yield of each is lessened. When the maximum acreage is dependent on artesian flow under these conditions, the installation of pumping machinery may become necessary in order to insure the continuance of an adequate water supply.

As against these disadvantages, which have been rather fully outlined, as is essential in any frank and therefore useful discussion, is to be placed regularity and relative constancy of the supply and its availability at all times, as compared with the fluctuations of surface waters unavailable except during the flood season to any but the owners of the oldest rights. An added advantage where the landowner owns his well is his complete control over his water supply. He may irrigate when and how he will, and thus most economically, and is not dependent upon the adjustment of supply among a number of users from a common source.

ORIGIN OF THE GROUND WATERS.

The ground waters of the San Joaquin Valley have precisely the same origin as its surface waters—namely, the rainfall and snowfall in the drainage basins tributary to the valley. They are in reality simply that portion of the surface waters that sinks into the sands and gravels of the valley floor and makes the rest of its journey seaward by slow percolation through the pores between the sand grains.

One of three things happens to the water that reaches the earth's surface as precipitation: (1) It returns directly to the air by evaporation from plant, soil, or water surfaces; or (2) it flows to the sea in surface streams; or (3) it sinks into the ground, and joins the body of water that saturates the soil particles below the ground-water level. It is with the latter part of the precipitation on the nearly 32,000 square miles of area included in the San Joaquin Valley and the mountain watershed tributary to it that we have to deal.

In the outline of the geologic history of the valley it has been pointed out that its entire surface is made up of the surfaces of contiguous alluvial fans, and that the valley is underlain to a depth that can not be determined accurately, but that doubtless runs into thousands of feet, by porous, unconsolidated, alluvial-fan material, mingled, in some areas, with lake deposits. This material has been transported from the mountains to the valley by the agency of running water. Many times its own volume of water has passed through and over it in the course of its removal from the mountains to the valley. It was deposited by and in water and has been more or less continuously saturated ever since.

A large but quite undeterminable portion of the run-off from the mountains each year sinks and joins the ground water. Of the 3,000,-000 acre-feet discharged annually into the valley south of the Kings River-San Joaquin divide, only the small portion that spills northward from Kings River itself reaches the sea over the surface, because there has been no outflow from Tulare Lake for forty years. The greater part evaporates or sinks to join the underground supply. Northward from Kings River the surface waters are greater in volume than south of it and serve effectually to keep the sands and gravels beneath them saturated.

UNDERGROUND CIRCULATION.

Underground waters near the surface usually move slowly in the direction of the surface slope and at rates that vary with the gradient of the slope and the coarseness of the material through which they percolate. The freedom of the outlet by which they escape is also important. They may be ponded by a restricted outlet just as surface waters may. Measurements of rates of ground water movements in the San Joaquin Valley are not available, but facts stated in the following paragraph indicate pretty plainly the conditions that probably prevail:

(1) The alluvial fans that make up the valley floor are generally of low slope and fine material. The fans of the Cañada de las Uvas and of San Emigdio Creek, at the south end of the valley, and of Pala Prieta and Los Gatos creeks on the west side are exceptions; but the streams that have produced them contribute so small a proportion of the ground waters that they may be disregarded. (2) The general slope of the lowest line of the valley, from the south to the north, is not only not continuous, in that it is interrupted by ridges like that north of the Tulare basin, but it averages only about 1 foot to the mile, a very low gradient for a semi-arid region. (3) The wells drilled throughout the valley prove that the sediments underlying it are all fine. (4) The surface outlet of the San Joaquin and Sacramento drainage is by way of Suisun Bay and the straits of Carquinez to San Francisco Bay; but the straits are restricted, and it is not probable that bedrock lies far beneath the surface in their vicinity. In short, there is no adequate outlet for the underground waters of the Great Valley, which is canoe-shaped, with only a notch in the rim at the straits through which the surface waters spill. All of these conditions favor slow movement of the underground waters about the borders and at the ends of the valley, with their practical stagnation along the lower San Joaquin because there is no adequate outlet for them there. To be sure, capillarity and evaporation afford some slight escape for the ground waters as they approach the surface in their slow movement along the

valley axis. The great alkaline areas of the east slope and of the valley trough indicate escape of underground waters, because it is by this escape that the alkalies are concentrated at the surface; but the outlet provided in this way is of slight consequence when compared with the total body of ground waters.

The belief that there is little movement in the subsurface waters of the lower San Joaquin is strengthened by a consideration of their chemical characteristics. Some of the ground waters of the upper deltas of the east side are among the purest waters of this type known, while those from the shallow flowing wells of the bottom of Tulare Lake and from the deeper wells of the north end of the valley are so heavily charged with mineral matter as not to be potable or suitable for irrigation purposes. Ground waters dissolve the soluble minerals from the rock fragments—the clay, sand, or gravel particles with which they are in contact. The amount thus dissolved depends upon the chemical combinations in which the minerals exist, some being much more soluble than others, and upon the length of time during which the waters are in contact with them. In general, the alkalies in the sands and gravels of the east side are in the most resistant form, the silicates of the granitic débris from the Sierra; the alkalies of the sands and gravels of the west side are in less resistant form, the sulphates and carbonates of the Cretaceous and Tertiary shales and sandstones; hence the ground waters of the high parts of the east slopes of the valley, which move with comparative rapidity, are much purer than the waters from similar situations on the west side. Furthermore, the volume of water poured out upon the east-side fans is many times greater than that discharged upon the west side, so that the alkalies dissolved are greatly diluted. But down in the trough of the valley, especially near its north end, the ground waters contain a much larger percentage of salts, even than those of the west side. If there were rapid circulation of ground waters here, this condition should not exist, for the dissolved salts should have been gradually carried out. The fact that the waters are highly mineralized is regarded then as additional evidence of sluggish circulation, or perhaps practical stagnation.

QUANTITY OF GROUND WATERS.

Little need be said of the quantity of the ground waters in the valley for two reasons: The first is that although it is clear that the quantity is enormous, it is not possible to estimate it with any exactness; the second is that the actual quantity is not of as much importance in its use as its accessibility and the rapidity with which it is restored when withdrawn.

The area of the valley is about 11,500 square miles. The depth of the sands and gravels which are saturated with the ground waters is

probably not less than a mile at the maximum, and may be much more. The average depth is equally unknown, but wells 1,000 or 2,000 feet deep, or even more, that are scattered throughout the valley, do not reach the bottom of the unconsolidated sands and gravels; so it may safely be assumed to be one-quarter of a mile and more. At this depth, nearly 3,000 cubic miles are saturated with ground waters, and if the porosity is 20 per cent, the conclusion is reached that 600 cubic miles of water underlies the valley—certainly a conservative estimate. But this includes water of all qualities and those found at great depths. Not all of the former are usable and the latter are not accessible.

ACCESSIBILITY AND AVAILABILITY OF GROUND WATERS.

One of the most important elements in the cost of ground waters, of course, is their accessibility, by which is generally meant the depth at which they stand beneath the surface; but the depth of boring necessary to develop them and, if pumped, the amount that they are drawn down when the pumps are in operation are also important elements.

The cheapest waters in general are those that flow out at the surface, even though deep wells may be necessary to develop them and the initial cost may therefore be great. But these waters may not always be most available, because they are to be had only in the lower parts of the valley, where, because of climatic conditions and alkalinity of soil, many of the lands are less valuable than those farther up the slopes. Generally speaking, about the borders of the valley the ground waters lie at the shallowest depths in the deltas and at the greatest depths in the interareas. The flood channels and the irrigation ditches are the lines along which recharge of the ground waters is effected; hence in their vicinity the ground-water level lies near the surface and the pumping lift is at a minimum.

Beneath the west side slopes, unfortunately, where the waters are most needed, they are not accessible. The conditions here illustrate well the dependence of the ground waters upon local surface supply. Surface run-off is most limited in this area, the ground waters lie at too great depth for profitable utilization, and they are usually too inferior in quality to be desirable even for irrigation.

DEVELOPMENT OF GROUND WATERS.

The development of underground water in the valley is as yet in its infancy. It does not compare in intensity with that in Southern California, where, with an irrigated district of about 225,000 acres, there are nearly 3,000 flowing wells, costing about \$675,000 and yielding nearly 200 cubic feet per second of water, and about 1,400

pumping plants in which \$2,500,000 are invested, by which an average of nearly 300 cubic feet per second of water are produced. Other minor wells increase the investment, but add little to the product. The total estimated investment in the development of ground waters, exclusive of the distribution systems, is about \$5,000,000 in this restricted district and the water produced is approximately 500 cubic feet per second. For comparison with this development south of the Tehachapi, the following estimates have been prepared from the records of the U. S. Geological Survey to indicate the relatively meager development in the San Joaquin Valley.

Ground water development in San Joaquin Valley.

County.	No. artesian wells.	Estimated cost.	Estimated yield, second-feet.	No. pumping plants.	Estimated cost, well and plant.	Estimated capacity, second-feet.	Estimated output.	Total cost.	Total yield.
Kern.....	112	\$161,400	73.46	104	\$138,632	225.84	$\frac{1}{2}$ capacity. 42.64	\$300,032	116.1
Tulare.....	124	189,968	23.31	191	244,098	162.72	$\frac{1}{2}$ capacity. 54.24	434,066	77.55
Kings.....	77	112,959	19.3	3	1,530	1.34	$\frac{1}{2}$ capacity. 5.24	114,489	19.54
Fresno.....	40	40,000	7.5	28	.....	30	5	.....	12.50
Madera.....	31	13,237	7.81	17	44,931	40.8	6.8	58,168	14.61
Merced.....	133	48,013	7.95	43	46,700	40.93	6.82	94,713	14.77
Stanislaus.....	5	3,830	1	9	.....	8.35	1.39	.....	2.39
San Joaquin.....	.....	.....	.....	202	123,836	250	41.67	.....	41.67
Total ..	522	569,407	140.33	597	599,727	759.98	158.80	1,001,468	299.13

The data upon which these estimates are based are neither as complete nor as satisfactory as those used in Southern California, and therefore the conclusions must be regarded as suggestive rather than as accurate in detail. As an example of one of the weak points in the estimates, attention may be called to the column in which the output of the pumping plants is recorded. Generally these plants are used in the irrigating of alfalfa or of garden products. Some of them are independent sources of water; others are auxiliary to gravity waters and are used only when the latter are not available; some are in the southern part of the valley, where the rainfall is less than 5 inches; others are in the northern part of the valley, where the rainfall is more than twice as heavy, and where on this account less water need be applied artificially. Of course the pumps are not in constant operation anywhere, but the percentage of the year that they are run varies with local conditions. No exact estimate of this percentage can be made, but it has been assumed in the estimates that the pumps are operated the equivalent of two months continuously, hence that their output for the year is one-sixth of what it would be were they in constant operation. This estimate is more likely to be too high than too low. In one county, Tulare, which includes the Portersville, Exeter, and Lindsay citrus districts, a larger

factor is used. Most of the pumps in this county are used for citrus irrigation, and it is assumed here that their output is one-third of what it would be were they in continuous operation. This estimate should not be excessive.

Accepting the estimates, then, as they are, we find that in the San Joaquin Valley there are at present between 500 and 600 flowing wells and a somewhat greater number of pumping plants, representing an investment of between \$1,000,000 and \$1,500,000, and yielding in the neighborhood of 300 cubic feet of water per second. The number of wells is about one-fourth that of Southern California, the investment is one-third, and the product about one-half, although the total irrigable area of the San Joaquin Valley is nearly ten times that of the southern field and the underground waters available are probably in similar ratio. This comparison, even though the figures upon which it is based are not complete, gives a graphic idea of the development that may yet be accomplished in central California by the full use of the ground-water resources.

COUNTY NOTES.

KERN COUNTY.

GENERAL CONDITIONS.

Kern County, which includes the extreme southern end of the San Joaquin Valley, receives its principal water supply, both surface and underground, from Kern River, which flows out upon the valley floor just above Bakersfield. Minor amounts, chiefly as winter flood waters, are contributed by Poso Creek and the streams that enter the valley from the south and west. The supply in excess of that used by the canal systems flows into Buena Vista reservoir, where it is stored for the irrigation of the Miller and Lux lands along the trough of the valley to the north. During seasons of particularly heavy stream flow, a portion of the water escapes northward along either the main channel or the Goose Slough channel to Tulare Lake.

In the course of its distribution over the delta lands through the canals in irrigation, and by flow through the natural distributaries, a definite portion of the water sinks and so maintains a condition of saturation of the sands and gravels that have been deposited in the course of the growth of the delta. These saturating waters, like the surface waters, move in the direction of the slope of the delta, but at a much slower rate. They circulate more freely through the coarser beds of the delta deposits, and as they pass beneath the finer beds that are more numerous in those parts of an alluvial fan that are most distant from its head, they accumulate pressure. Therefore when the confining beds above them are pierced by a well they rise,

and if the pressure is sufficient they flow over the surface. These are the flowing artesian wells of the Kern and Buena Vista lake beds and the region extending some miles north of them, and of the main San Joaquin Valley artesian basin, beginning in the neighborhood of Button Willow and extending thence northward down the San Joaquin Valley to the delta of the San Joaquin and Sacramento rivers. It may connect with the Buena Vista artesian area, although there is no evidence available now to determine this point.

FLOWING WELLS.

In 1905 there were 112 flowing wells in the county that were examined, and there were doubtless a few more that were not seen. The yield of these was in the neighborhood of 70 or 75 second-feet. About one-third of the wells were used for irrigation, the remainder being used for stock or domestic purposes or allowed to waste uselessly. The areas in which they occur are indicated by the outlines of the artesian basins, as shown on Pl. I.

Generally speaking, the artesian pressures have not been seriously affected by the developments that have taken place to date, although there are some wells, as in the Semi-tropic district, whose flow has decreased markedly as a result of the boring of big wells near by, but on lower ground and therefore in more favorable situations. Artesian wells usually deteriorate with age, as a result of any one of several causes, as slow filling with sand, clogging by gelatinous deposits, the growth of microscopic organisms, and, finally, by the deterioration of the casing.

The State engineering department of California measured the yield of certain flowing wells in the Kern delta in 1885, and some of these were remeasured in 1905. The remeasured wells show decreases in yield varying from 50 to 100 per cent, but in only one of the wells available for comparison has there been complete cessation of flow. Decrease in yield of individual wells as development progresses is so usual a phenomenon that no community can safely plan its future on the assumption that a cheap supply of this type will remain constant, even in such large basins as those of the San Joaquin. But flowing water should be available for years from those wells whose initial yield is sufficiently large to be of value. Later, when the communities are more thickly settled and the wells are so closely grouped that flow and yield are materially decreased, industrial conditions may have so changed that pumps can profitably be installed to augment the supply. The cost of such pumped waters will usually be particularly low because of the slight lift required to bring them to the surface.

PUMPING PLANTS.

More than 100 pumping plants in Kern County develop underground water for various purposes. Of these about 40 are gas plants, 25 are steam plants, and the rest are electric. The developed waters are used for irrigation, for city supplies, for engine waters, and as supplies for steam plants, as at the pumping stations of the Pacific Coast Oil Company.

In the district about Bakersfield 50 pumping plants are in use to develop irrigation water. Half of these are electrically operated and belong to the Kern County Land Company. Each of these plants is equipped with 30 or 40 horsepower motors directly connected with No. 8, 10, or 12 centrifugal pumps. Each pump is connected with from three to five 13-inch wells, the number being determined by the yield of each well. From the data collected on these wells, the following cost averages were computed, on the basis of the quoted charge of 15 cents per horsepower per 24 hours, for the electric power used.

Data concerning pumping plants in Kern County.

Average depth to the water from the surface, in feet.....	10
Average suction 20 feet. Average total lift, in feet.....	30
Total yield of 25 plants, in second-feet.....	100.34
Total horsepower consumed.....	860
Total cost per day to develop 100.34 sec. feet, 860 H. P., at 15 cents.....	\$129.00
Cost per second-foot for 24 hours.....	\$1.29
Cost per acre-foot of water developed.....	\$0.65

E. M. Roberts, of Bakersfield, has furnished the following data as to cost of operation on a privately owned steam plant, which has a particularly advantageous location:

Data concerning steam pumping plant at Bakersfield.

Equipment: 30 H. P. steam engine, No. 12 centrifugal pump, five 15-inch wells 40 feet deep; 6 feet to water, 15-foot suction, 21 feet total lift:	
Cost of crude oil (fuel) and lubricant for 24 hours.....	\$2.25
Cost of labor 24 hours.....	\$4.00
Total cost.....	\$6.25
Yield of plant.....	7 second-feet.
Cost per second-foot for 24 hours.....	\$0.89
Cost per acre-foot of water developed.....	\$0.45

Neither of these estimates makes any allowance for interest on investment in well and plant nor for deterioration, hence the costs as given are somewhat too low. It must be remembered, moreover, that Mr. Roberts's plant is in a particularly favorable situation, being close to the banks of the Kern, where the supply is regular and the lift slight. The standard of water costs in this district is set by the

price of gravity water from the Kern, 75 cents per second-foot for 24 hours, or about 38 cents per acre-foot, where distribution is affected by sales.

The pumped water therefore costs from 20 to 100 per cent more than the gravity water, and its cost will increase as it is developed from deeper strata with higher lifts. It seems to be quite generally believed locally that water at these prices can not be used profitably.

This may be true with the wasteful methods employed, the excessive amounts of water often applied, the class of crops produced, and the general lack of intensive cultivation; but it has been clearly proved in other communities and by individual experiences in the Bakersfield region itself that with more diversified or better selected crops, smaller individual holdings, and more intensive methods of farming, good profits may be made from the alkali-free lands of the delta and plains by the careful use of water at these or at even higher prices. It is safe to predict that the most important future developments in Kern County will result from the application of these principles.

Under any conditions that are likely to obtain in the near future it is not to be expected that ground waters at greater depths than 25 or 30 feet below the surface as an extreme will be usable for irrigation purposes. Water at this or less depth exists, of course, throughout the artesian areas along the lowest parts of the valley. It is to be found also throughout the greater part of the Kern delta and in the lower parts of the Poso Creek delta from a point about halfway between Famoso and Wasco westward. Near the foothills on each side of the valley, the ground water is not accessible except under unusual conditions, as in the flood plains of the larger rivers, or in areas where particularly valuable products, such as citrus fruits, will justify the expense of pumping to exceptional heights. In the intermediate areas between the deltas of the streams that supply the ground water, it is also apt to be too deep to be accessible. This condition is illustrated in the area between the Kern and Poso Creek deltas, east of Shafter station, on the Santa Fe railroad, and in the region between Delano and the foothills just south of the Tulare county line.

Near the northern edge of the county the main artesian belt of the valley, whose southern end is in the vicinity of Button Willow, expands to a width of 26 or 27 miles measured along the county line. Much of this central portion of the valley along the north edge of Kern County is in large holdings and is therefore but thinly settled, but developments are ample to prove the artesian conditions and to permit outlining the artesian belt with a fair degree of accuracy.

The outlines as determined are shown on the accompanying map (Pl. I), which also shows by means of hydrographic contours the depth to the ground-water level outside the artesian limits.

Although little direct evidence bearing upon this point exists, there can be no doubt that beneath the broad, steeply sloping west-side plains of Kern County the water is too poor in quality to be usable, except perhaps for stock, and that a few miles back from the trough of the valley it is too deep to be accessible. Generally, the water table beneath these west-side plains has but little slope, the depth to it at any point being approximately equal to the elevation of that point above the trough of the valley.

TULARE COUNTY.

GENERAL CONDITIONS.

Tulare County, lying north of Kern and east of Kings, includes the eastern edge of the large central artesian basin at its widest part, all of the delta of Kaweah and Tule rivers and a part of that of Kings River, and the famous citrus region of the foothills and the higher parts of the valley floor about Porterville, Exeter, and Lindsay. It also includes, in the southwestern corner, a part of the old bed of Tulare Lake and a part of the district submerged during the last extremely high water, in 1880. The high water of 1905-1907 did not quite reach the Tulare County line.

Kings, Kaweah, and Tulare rivers are the chief sources of such additions to the ground waters as are made in this county, as they are the sources of the surface waters used by the various canal systems.^a Each of these streams has a distinct though rather flat delta, and the attitude of the ground-water plane indicates that the stream channels and canals along the crests of the deltas are the direct sources of the ground waters in the higher portion of the valley within Tulare County, and that from these lines of supply the waters percolate toward the lower parts of the valley and toward the areas between the deltas. These interareas receive only the slight direct supply from rainfall and from the minor streams that drain the foothills.

Within the artesian basin south and west of Tulare the ground waters, although receiving local additions within the county, are a part of the general body of ground waters of the central valley, stored there as a result of accumulation from all sources during centuries past, and are in general slow in motion northward along the valley axis.

^a An account of these systems was published in Water-Supply Papers, U. S. Geol. Survey, Nos. 17 and 18. These papers are not now obtainable, but may be consulted in libraries.

FLOWING WELLS.

In the 365 or 370 square miles of artesian-water land within the county there were about 125 flowing wells in 1905, representing an investment of between \$150,000 and \$200,000. Nearly 100 of these wells were used for irrigation, and the combined yield of all of them was estimated at less than 25 second-feet. The greater number of them are 7 inches or more in diameter, while a few old wells are of smaller bore. They are most numerous on the Kaweah delta west of Tulare and somewhat farther south, west of Tipton and Pixley. Pasture lands, alfalfa, gardens, deciduous fruits, and vineyards are irrigated by the use of the waters developed.

PUMPING PLANTS.

Irrigation by the use of pumped water is more extensively practiced in Tulare County than anywhere else in the valley. This is due to the development of citrus culture along the foothills between Tulare River and Kaweah River, where methods in vogue in the citrus districts south of the Tehachapi have been introduced. There were in all about 170 pumping plants in use for irrigation in 1905 while a number of others were in use for domestic or town supplies. Of the total number, 125 were electrically driven and procured their power from one company; 45 were gas or steam plants.

These plants are adapted to a wide variety of conditions, some of them pumping from wells in which the water stands at the surface, and others lifting it from a depth of 100 feet. In the irrigation of some of the hillside citrus groves water is forced to heights of several hundred feet, usually from a reservoir into which it is pumped from the wells. The best equipped plants that overcome lifts of less than 75 or 80 feet use centrifugal pumps directly connected with motors; when the lifts are greater some form of deep-well plunger pump is used.

In the Lindsay district the ground-water level varies greatly each year, falling during the pumping season and rising again in the winter and spring. To keep the pumps and motors within the suction limit during the low-water period, and at the same time prevent their submersion during the winter season, some of the ranchers have adopted the plan of placing the machinery in a tank. In one plant examined, the motor and pump were fastened to a movable platform that could be raised or lowered in adjustment to the varying ground-water level.

The Badger Irrigation Company at Exeter has a particularly interesting plant because of the high lift of waters for irrigation purposes. There are three substations in the lowlands that deliver water to several citrus tracts at the base of the foothills, and to a

large reservoir. From this reservoir the water is forced on up the hill by a special design triple-plunger pump operated by a 75 horsepower motor. This pump has a capacity of 75 miner's inches from the 66-foot lateral to the 247-foot lateral; of 53 miner's inches from the 300-foot lateral to the 400-foot lateral; and of 36 miner's inches from the 530-foot lateral to the 586-foot lateral.

Difficulty was experienced when the plant was first installed because the pipe used was too light to resist the great pressure. At present three-eighths inch cast iron pipe of 6, 8, and 10 inch diameter is in successful use.

COST OF PUMPED WATER.

The charge made for power in this district by the Mount Whitney Power Company is \$50 per year per horsepower for current used continuously, which equals 13.7 cents per horsepower for 24 hours; \$30 per year per horsepower for current used in daylight only, which equals 8.8 cents per horsepower per day of 12 hours.

Estimates were made of the yield and cost of water from 50 plants using power on the first basis, with the following results:

Cost of water at fifty plants.

Average lift, in feet.....	79
Total yield of 50 plants, in second-feet.....	24.5
Total horsepower consumed.....	509.6
Total cost per day, 509.6 horsepower at 13.7 cents.....	\$69.81
Cost per second-foot per day.....	\$2.85
Cost per acre-foot.....	\$1.43
Cost to lift 1 second-foot 1 foot for 24 hours.....	\$0.036

Another estimate is given below of the cost of water from another group of 8 plants in the same district:

Cost of water at eight plants.

Average lift, in feet.....	30
Total yield, in second-feet.....	8.44
Total horsepower consumed.....	106.9
Total cost per day, 106.9 horsepower at 13.7 cents.....	\$14.65
Cost per second-foot per day.....	\$1.75
Cost per acre-foot.....	\$0.88
Cost to lift 1 second-foot 1 foot for 24 hours.....	\$0.058

These estimates indicate in a general way what irrigators are doing in this district under present conditions.

PERMANENCE OF THE GROUND-WATER SUPPLY.

Most artesian basins are very sensitive to development, old wells decreasing in yield as new ones are installed, the shallow wells and those about the upper, outer edge of the basin being the first to show signs of failure. Diminution in the flow of the less favorably

situated wells will take place in actual practice long before the basin is overtaxed, hence some alarm is likely to be felt and some individual loss may occur before alarm is justified by conditions. In addition to the normal diminution of flow in wells due to physical deterioration in casing or to other causes not related to a general loss of head and reduction in supply, a new well drilled in the neighborhood of an old one, or so situated as to draw in part from the same general zone of saturated porous materials, will affect the yield of the first, although the combined yields of the two are much greater than that of either alone and much less than the supply.

Until wells are withdrawing water from an area more rapidly than it is supplied, even though there may be reduction in the yield of individual wells, there is no cause for alarm. It is difficult to determine when this point is reached in an artesian basin because diminution in flowing wells begins soon after development has begun, but when waters are pumped it is less difficult to tell. The continued lowering of the ground-water level in a pumped well, through years of average or abundant rainfall with gradually increasing lifts and correspondingly increasing costs, indicates overuse.

A comparison of the flows of a number of artesian wells in Tulare County, measured first by the California State engineering department in 1885, and twenty years later by the United States Geological Survey, indicates, as is to be expected, a general diminution of yield, this decrease varying from 40 to 90 per cent. A part of it is undoubtedly due to the installation of new wells in recent years, but much of it is to be accounted for by the clogging and filling of the wells and the rusting of the casing. In any event the losses are not serious, and in view of the immensity of the basin and the large supplies that reach it annually, it can not be considered to have approached the point of overuse.

This observation, however, does not hold for some of the areas in which pumping is most intense. The lands favorable for citrus culture are distributed along a frost-free belt on the lower foothills and adjacent high parts of the valley floor. The zone of most intense pumping is along the eastern edge of the valley, between the deltas of Tulare and Kaweah rivers. The ground waters here receive some slight accessions from local run-off from the foothills and from minor streams that flow out from them, but their principal source is the constant supply that sinks in the deltas of the major streams and percolates thence slowly in all directions.

On the deltas themselves, especially along their lower portions, where so much damage has been done in recent years as a result of over-irrigation, the consequent rise of the ground-water plane and with it the alkali, pumping is most helpful; in fact, pumping will doubtless be one of the means by which the damage done by over-irrigation in the past will be remedied in the future; but in Tulare

County pumping thus far has been concentrated, upon those points remote from the deltas and from the trough of the valley, where supplies are least rapidly replenished. As a result there has been a noticeable lowering of the water plane in recent years and an increased cost of the water product. As a matter of safety to the orchards already producing, means should be taken to prevent the installation of additional pumping plants in those parts of the citrus belt where development is now most intense and the effects upon the ground water have been most clearly discerned, for it is obviously more important to protect the orchards that are already producing than to plant more.

KINGS COUNTY.

GENERAL CONDITIONS.

The valley portion of Kings County includes the present and past Tulare Lake bottoms and the southern slope of the lower Kings River delta. Tulare basin is the lowest point in the southern section of the valley and is the area in which all surplus waters from Kings River southward accumulate. The flood waters of Kings River are divided on its delta, part of them flowing northward to join the San Joaquin drainage, while the other part flows into Tulare Lake. During years of low or moderate snowfall and rainfall in the Sierra, practically all the flow of Kern, Tulare, Kaweah, and Kings rivers is used in irrigation, and there is but little excess to escape to the basin; but during years of heavy precipitation great volumes of water accumulate in the Tulare lowlands. This basin is very shallow. Its shores have gentle slopes, hence the area of the lake fluctuates widely, with slight changes in the depth of the water in it. Since settlement began in the San Joaquin Valley it has had a complex history. Grunsky has summarized what is known of its earlier history in Water-Supply Paper No. 17,^a pp. 16 and 17. From his account that part of the following résumé which deals with conditions prior to 1897 is condensed:

Résumé of history of Tulare Lake.

1853. High.

1853-1861. Subsidence; elevation of surface in 1861, 204 feet.

1861-1863. Rapid rise to highest known stage, 220 feet above sea level, overflowing into San Joaquin River; area about 800 square miles.

1863-1867. Decline to about 208 or 209 feet above tide.

1867-1868. Filled again to about 220 feet above tide.

1872-1876. Fluctuated between 211 and 217 feet.

1876-1883. Decline to 192 feet; lowest stage then known.

1883-1897. Fluctuating; generally low.

1897-1905. Decline; dry in autumn of 1905.

1905-1907. Rise; elevation of water surface in summer of 1907, 193 feet; area of water surface summer of 1907, 300 square miles.

^a This paper is not now available for distribution.

A knowledge of the history of this lake makes clear the origin and character of the soils of all except the northern part of Kings County, where the alluvial-fan or "delta" conditions so general in the San Joaquin valley prevail.

Evidences of the former occupancy of the lowlands by the lake appear everywhere. Faintly marked sandy beaches encircle the depression at various elevations and over these beaches are strewn the shells of the mollusks that lived in the lake. In its lowest parts, dry and planted in grain in 1905, the fine sediments that settled in the lake bottom make a fertile alluvial soil.

It is to be presumed that the history of the lake for many centuries has been like that part of it which we know directly, i. e., that it has fluctuated in area and depth, occasionally drying out completely, then filling to the point of overflow. Under such conditions relatively little of the water which it has contained can have escaped by surface overflow; the greater part of it has evaporated or has been absorbed by the sands and silts of the lake bottom.

With the shrinking of the lake during the years preceding the inflow of 1906, its old floor was placed under cultivation and valuable crops of grain were produced. This successful grain culture proves the nonalkaline character of the present surface of the old lake bottom, but the saline waters yielded by numerous shallow flowing wells within it indicate the presence of alkalis at slight depths. The few wells available as evidence in and about the borders of the old lake, however, indicate that the deeper wells obtain the better water.

Most of those that extend to depths of 1,000 feet or more develop waters sufficiently pure for irrigation or for drinking purposes.

FLOWING WELLS.

There are probably as yet less than 100 flowing wells in Kings County (77 were visited by Geological Survey representatives in 1905), yielding approximately 20 second-feet. Probably not more than one-third of the wells are used for irrigation, a large number of small-bore shallow wells being used for stock and for domestic purposes. The northern part of the county, in the vicinity of Hanford, Armona, and Lemoore, is well supplied with surface water by the canal systems that head in Kings River, and is a most productive, thoroughly cultivated area. Ground waters are not needed and no serious attempt has been made to utilize them here.

In the vicinity of Corcoran, Waukena, and Angiola, however, a successful colony has been established that depends almost entirely upon ground waters. A number of deep wells have been put down to depths of 900 to 1,600 feet, which yield flowing waters in amounts ranging from 5 to 40 miner's inches. Shallow wells have also been

bored and pumping plants have been installed over them. The tract includes about 30,000 acres, and alfalfa, cereals, sugar beets, dairy and garden products, and fruits are produced successfully.

FRESNO COUNTY.

GENERAL CONDITIONS.

Because of the fact that San Joaquin River forms the boundary that separates it from Madera County, Fresno County extends 25 or 30 miles farther north along the trough of the valley and along the west side than along the east slope. Thus the greater part of its lowland area is in arid west-side plains and in the relatively thinly settled central valley between Kings River at Lemoore and Laton and San Joaquin River at Mendota and Jameson.

Its best known, most densely populated, and most productive area is, of course, that about the city of Fresno, on the middle east-side plains, on the Kings River delta. This rich and populous region is irrigated by gravity water, distributed by a network of canals that take their supply from the river. These irrigation systems have been fully described by Grunsky.^a

A later Water-Supply Paper, by Lippincott,^b dealing with the possibility of storage and the development of water power on Kings River, embodies the results of a close study of the ground waters and their relation to alkaline conditions by Louis Mesmer and Thomas H. Means. From this report the following quotations are taken:

The natural drainage of these lands is toward the southeast at the rate of about 6 feet to the mile. The soil is largely granitic sand, and below an average depth of 10 or 15 feet it is saturated with water. The surface water is somewhat alkaline and therefore it is not advisable to pump it for irrigation. Water below a depth of 50 feet can be considered satisfactory for irrigation. This is based on tests of more than 800 wells in the district, some of them being in sections where there were the strongest surface alkaline indications. In every case this lower water was found to be good, and when the strata near the surface are penetrated it rises to the elevation stated. There have been few attempts to pump water in larger quantity than is required for domestic purposes. A 2-inch screw pipe, put down to an average depth of 50 feet, landing the pipe on a stratum of clay, and then boring through the clay and allowing the water to come in from the bottom of the hole, is always ample for this purpose.

* * * * *

A few small pumping plants have been installed—one 5 miles east of Fresno, on the Minnewawa ranch; several around Selma, and two near Wildflower—which yield at least 0.5 second-foot to a 7-inch unperforated well not more than 70 feet deep; with a lift not to exceed 20 feet in any case. Wells of 10-inch or 12-inch casing should be put down to a depth of about 100 feet on an average and should not be perforated above 50 feet below the surface, thus shutting off all possible chance of drawing from the more or less alkaline surface water. It is probable that wells of this size and depth would each furnish 1.5 second-feet. * * *

^a Water-Supply Paper, U. S. Geol. Survey, No. 18, p. 39 et seq. Out of print. May be consulted in libraries.

^b Water-Supply Paper, U. S. Geol. Survey, No. 58. Out of print. May be consulted in libraries.

The result of pumping, * * * would be to improve the conditions rather than to increase the troubles from alkali. The water table would be lowered sufficiently to permit the washing down of the alkali salts, and the salts, instead of being confined to the surface layers of the soil, would gradually be distributed * * * and thus rendered harmless. The lowering of the water table would be of the greatest assistance in the reclamation of the lands already alkaline, and would probably permit this reclamation without extensive underdrains.

In a report by Lewis A. Hicks on the "Generation and transmission of electric power and installation of pumping plants," included in Water-Supply Paper No. 58, an estimate has been made of the cost of water pumped from the ground-water supply by electric power generated on Kings River. The estimates are made on the basis of 100 pumping stations, each with a maximum capacity of 5 second-feet and an average lift of 45 feet, and the probable cost of the water produced is given as 50 cents per acre-foot when the pumping plants operate 328½ days per year and \$1.43 when the pumping plants operate 100 days per year.

Among the conclusions reached by Mr. Lippincott after a thorough investigation of conditions on the Kings River delta are the following:

(5) Pumping plants can be established and operated which will furnish 1,000 acre-feet of water every day at a cost not much greater than that now paid for gravity water from the canals, to supplement the present summer supply or to extend the irrigated areas.

(6) The operation of the pumping plants will partially, if not wholly, prevent the rising of alkali to the surface of irrigated lands.

The rise of the ground waters presents a difficult problem in practically all of the delta lands of the San Joaquin Valley, and is merely particularly well exemplified in the Kings River delta in Fresno County. Mr. Grunsky states that the rise in ground waters since the beginning of irrigation is from 10 to as much as 50 feet in parts of the delta. One great difficulty that arises in dealing with the problem is due to the fact that the injury is done in one locality while a large part of the cause may be in another. The lower part of the delta lands are the chief sufferers from the rise of the ground waters, but the cause is to be found in the irrigation on the higher lands as well as on those affected. Over portions of the central artesian basin and about its borders the ground waters have always stood close to the surface, and much of the land was alkaline before there was any settlement in the valley. The effect of the irrigation on the higher lands has been to extend this saturated and alkaline zone slowly up the slope toward the eastern margin of the valley. As a result of this extension it has encroached to a certain extent upon lands that were valuable.

Without storage the gravity waters will not serve an acreage greatly in excess of that supplied by them now, and the pumping plants that must be installed to secure future growth will in addition

serve a most valuable function in drainage, tending to prevent the extension of alkaline conditions and aiding in the reclamation of lands already alkaline.

FLOWING WELLS.

The flowing wells of the artesian belt of Fresno County are sparsely scattered over a broad area along the trough of the valley. There are only about 40 of them, all told, and they range in depth from less than 100 to 1,500 feet, the latter being the depth of one of the wells belonging to the Johns estate, north of Summit Lake. In the district adjacent to Lemoore, south of Kings River, small flows, sufficient for stock and domestic purposes, are obtained at 150 feet and less; but farther north no shallow wells are found.

Those on the James and Herringhouse ranches, south of the San Joaquin River, are 600 to 800 feet deep. The flowing wells of the larger ranches were bored generally to obtain a supply of water for stock at times when none is available in the sloughs and irrigating ditches. Irrigation in these large holdings is as yet accomplished only during the flood season when abundant gravity water is available for lavish use. The possibility of using ground waters for such purposes is scarcely considered, although on one of the James ranches the water from a flowing well is used to irrigate about 50 acres of alfalfa.

The waters west of the San Joaquin River in Fresno County, whether within or without the flowing-well area, contain large proportions of salts in solution. This is a condition that is true of west-side waters everywhere within the valley, and apparently of all very deep waters near its northern end. South of Mendota, where the river no longer forms the eastern border of the county, the area within which waters of the east-side type appear extends 5 or 6 miles east of the valley axis. All of the waters of the upper east slope are very pure, but as they approach the lowest part of the valley they gradually assume the character of the waters there. In addition to the increase in the percentage of dissolved solids from the east toward the west across the valley, there seems likewise to be an increase from the south northward. The shallow flowing wells of Lemoore and vicinity contain very moderate amounts of salts in solution, while those in the vicinity of Mendota and Firebaugh and farther north carry from 1,000 to 20,000 or more parts per million.

The great west-side plains, with their productive soil, freedom from hardpan, good drainage, and favorable situation, are nonproductive because of their aridity, and must remain so until water can be applied to them. The ground waters beneath them are poor in quality and are deep. The ground-water plane seems to be nearly horizontal, such evidence as is at hand indicating a slope of only about 2 to 5 feet

per mile; hence it is nearly as far to ground water beneath any part of these plains as the plains themselves are above the lowest part of the valley. If experiments should prove that they will successfully produce citrus fruits or other high-priced products, then it may be that water can be pumped to them from the valley and the venture made commercially practicable despite the great expense involved, for it is to be remembered that water is pumped to heights of several hundred feet in Tulare and San Bernardino counties in localities where it can be used on good citrus lands with an excellent margin of profit.

At present the west slope is nearly without permanent residents. There are perhaps a dozen settlers between Panoche Creek and the Coalinga Branch of the Southern Pacific. Sheep camps, occupied temporarily in winter, are scattered over them. In the early nineties a few seasons of heavy rainfall led to settlement about Huron, and two or three crops of grain were harvested, but since then there has not been sufficient rainfall to mature a crop, and the plains have been abandoned to the sheep men who rent the grazing privileges from the large landholders, notably the Southern Pacific Railway Company, for 6 cents per acre per annum.

MADERA COUNTY.

GENERAL CONDITIONS.

The valley portion of Madera County is limited on the south and west by San Joaquin River and on the north by the Chowchilla. Irrigation by the use of surface water is practiced about Madera through the utilization of Fresno River waters in the early summer, when they are available, and about Minturn, near the north edge of the county, by the similar use of Chowchilla River waters. Both of these streams have small mountain drainage basins, so that the flow from them is not prolonged late into the summer.

The extreme western edge of the county is also under irrigation from gravity waters. The Chowchilla canal heads on the north side of the San Joaquin, about 6 miles east of Mendota, and runs northward, generally parallel to the river, for about 20 miles, commanding a strip 5 or 6 miles wide between it and the river. The greater part of the rest of the county is as yet grain land or pasture land, intensive cultivation being practiced only locally.

FLOWING WELLS.

The ground waters have not been drawn upon to any extent for irrigation in the developments that have taken place thus far. There are about 30 flowing wells in the 350 square miles of artesian water-bearing land in the county, and these are practically all used for watering stock on the Chowchilla ranch and the Miller and Lux

properties. The total yield for all of the flowing wells is estimated to be less than 8 cubic feet per second, although at least one of the individual wells yields more than 1 cubic foot per second. These wells are generally shallow, depths of 200 to 400 feet being usual. Some of them are among the oldest in California, having been drilled nearly forty years ago, and while there has been some lessening in yield it is undoubtedly due to deterioration of the casing and to clogging. A table of measurements made at different periods is appended:

Yield of flowing wells in Madera County.

Location.	Yield in miner's inches.		
	1871.	1884.	1905.
Sec. 21-10-14.....	20	13	10
Sec. 4-11-15.....	22	18	11
Sec. 23-10-15.....	4	6	.....
Sec. 16-10-14.....	1.1	3	12
Sec. 23-10-13.....	.....	5	2
Sec. 14-10-13.....	.....	23	12

The well in section 16-10-14 was recently cleaned and responded with a stronger flow than it had ever yielded before. The fact of a well-maintained pressure and supply is further indicated by the strong flows of new wells put down in the vicinity of older ones, tapping the same water bearing beds.

It is evident that these cheap waters can be developed in large volume in the western part of Madera County if it is desired.

PUMPING PLANTS.

About 15 pumping plants in the county are used for irrigation. Most of these are in the vicinity of Borden, where the ground-water level lies at a depth of from 10 to 20 feet. The pumps pull the water level down locally 15 or 20 feet, so that the total lift is usually 25 to 40 feet. Irrigators estimate that under these conditions they can deliver water for about 75 cents per acre-foot for fuel and labor. Even lower figures are given for the best equipped plants. The following estimates are recorded from the plant of A. L. Sayre:

Estimated cost of pumping water in Madera County.

Equipment, 60 horsepower gas engine, No. 10 centrifugal pump. Three 10 and 12 inch wells, 110 feet deep; depth to water, 16 feet; suction, 22 feet; total lift, 38 feet.	
Cost of fuel per day of 24 hours.....	\$5. 47
Cost of labor per day of 24 hours.....	3. 35
Total.....	8. 82
Yield of plant, second-feet.....	6. 23
Cost per second-foot for 24 hours.....	\$1. 41
Cost per acre-foot.....	\$0. 71

Interest on investment and deterioration of plant, of course, increase this cost somewhat; yet, it is certainly well within the limits of profitable use. Practically everywhere within that part of the county west of the Southern Pacific, except near the bluffs of San Joaquin River, pumping waters are accessible. As the foothills are approached, depth to ground water increases and the lift necessary in their development increases correspondingly.

MERCED COUNTY.

GENERAL CONDITIONS.

Merced County, unlike Madera County, extends entirely across the San Joaquin Valley and thus includes both east-side and west-side conditions. The gradual amelioration northward of the aridity of the south end of the San Joaquin Valley becomes noticeable at this latitude; hence, the raising of grain without irrigation, which is possible on the east side as far south as Fresno County, is usually successful on the west side in the northern part of Merced County.

Irrigation by surface waters is accomplished principally by the utilization of San Joaquin and Merced River waters. The lower line of the San Joaquin and Kings River canal, which leaves the river near Mendota in Fresno County, extends entirely across the west side of Merced County and into Stanislaus County. The high-line canal of the same system also extends from the southern to within a few miles of the northern edge of the county. This irrigation work commands much the larger portion of the west-side plain. The zone of unwatered land, between the high-line canal and the foothills, is relatively narrow.

The most important east-side system is the Crocker-Huffman canal, which taps Merced River about 2 miles below Merced Falls and serves an extensive section east and north of the county seat. The Stevenson-Mitchell canal heads in San Joaquin River about 14 miles southwest of Merced and commands a belt from 3 to 4 miles wide between this point and the mouth of Merced River. The principal settlement below this canal, the Stevenson colony, is between the lower Merced and the San Joaquin.

North of Merced River, the Turlock irrigation district extends into Merced County from Tuolumne County, in which lie the greater part of the lands covered by the system. In addition to these major systems, there are a number of minor canals along the Merced River bottoms. On the whole, however, the county is thinly settled and but a small portion of it is under irrigation. Perhaps three-fourths of the valley lands are devoted to dry farming, the production of hay and grain, or to pasturage.

The territory east and north of Merced, the Plainsburg and Le Grand districts in the southeastern part of the county, much of the foothill area, and the greater part of the strip on the north side of Merced River are producing hay and grain, while the greater part of the area between the Southern Pacific Railway (main line) and San Joaquin River is in pasture. Part of this pasture land was at one time tilled, but for various reasons, among them the rise of alkali, tillage has ceased, and the lands have been returned to pasture. On the west side the strip above the canals and between them and the hills is generally in grain from Dos Palos northward. South of Dos Palos this strip is utilized principally as sheep range.

FLOWING WELLS.

The use of ground waters, like surface irrigation, is more usual in Merced than in Madera County, although it has not as yet become extensive in either area. The total number of flowing wells in the county is between 125 and 150. The greater number of these wells are shallow, from 100 to 400 feet deep, and their yield is correspondingly small. As the most of them were drilled twenty or twenty-five years ago, not for irrigation but for domestic purposes and for stock, they fulfill the function for which they were intended. Of the 133 wells of which the Geological Survey has records, but 15 are reported as used for irrigation, and even these are generally used on a small alfalfa patch or garden of but little importance. The total yield of all the flowing wells in the county is estimated at less than 8 second-feet. That large yields may be secured is indicated by the experience of the Crocker-Huffman Company in sinking a 2,000-foot test well for oil in the spring of 1902 in sec. 15, T. 7 S., R. 13 E. No oil was found, but this well, although near the eastern edge of the flowing well area, as indicated by the shallow developments to date, yielded what is reported to have been the largest flow in the Merced district. When the casing was pulled the flow ceased, doubtless because of leakage into the upper strata. The water is said to have been soft and of fine quality.

By far the greater number of the flowing wells in the county are on the east side, south and west of Merced. The west-side developments are very meager. This is doubtless due in part to the fact that the San Joaquin and Kings River canal system supplies plenty of cheap gravity water to this district, but it is affected also by the fact that the west-side underground waters are of inferior quality. The flowing wells particularly, which must be deep, yield very bad waters. Some of them are too saline for irrigation. A few of the shallow wells near the main canals or the large laterals supply water sufficiently soft for any purpose. Most of the deeper waters along the axis of the

valley, as well as those along the west side, are alkaline. The experience of some of the irrigators in the Stevenson colony, who have found that the waters from certain flowing wells can not be used safely in the irrigation of fruit, proves this. In general, it may be said that the best ground waters are found well up the east slope, and that there is a progressive deterioration westward.

PUMPING PLANTS.

There are between 40 and 50 pumping plants in the county, most of them equipped with gas engines. More than half of these are used to develop irrigating waters, and the remainder are used chiefly for domestic or town supplies. Grain, fruit, alfalfa, berries, sweet potatoes, etc., are the principal crops raised by the ranchers, who use pumping plants for irrigation. They express themselves as satisfied with the results and convinced that pump irrigation in many parts of Merced County may be made highly successful.

In the Atwater and Livingston districts, as well as about Plainsburg and Le Grand, plants have already proved practicable. Throughout much of the east side, to the west, south, and east of Merced, the ground-water level is within 20 feet or less of the surface, and where soils are favorable, such accessible ground waters may be utilized to advantage in pumping operations.

Merced, like other east-side counties, includes a belt between the trough of the valley and the foothills that contains more or less alkali because of the proximity of the ground waters to the surface. In certain parts of this belt alkalinity has increased in recent years as the result of irrigation by means of gravity waters supplied by the Crocker-Huffman system. In such areas, if the lands are still productive, pumping, either as an independent source of irrigation water, or as an auxiliary to the gravity system, is most to be desired. It results in benefit to the community in several ways. In the first place, it is a method of drainage. The water that is supplied to the land is drawn from beneath it. The tendency of the ground waters to rise with irrigation is thereby counteracted and the ground water level is kept down. In the second place, there is no overuse. Each acre-foot of water developed costs a fixed sum. Under these conditions more will not be used than is needed and the usual tendency of the ground-water plane to rise with irrigation will not be manifest. Again, pumping and the use of relatively high-priced water encourages intensive cultivation and this again reduces the quantity of water necessary. Frequent cultivation and the creation thereby of a mulch at the surface has long been recognized as one of the effective means of prevention of loss of water by evaporation from the surface. Whether lands already damaged by alkali as a result of the applica-

tion of too much water can be reclaimed and utilized by pumping, under the economic conditions that now exist, is an unsettled question; but there is no doubt that the irrigation of undamaged lands whose water plane lies within 20 or 25 feet can be carried out successfully where intensive farming methods are used, and that the rise of alkalies in such lands will be prevented.

STANISLAUS COUNTY.

GENERAL CONDITIONS.

Stanislaus County, like Merced, extends entirely across San Joaquin Valley, and therefore both east-side and west-side conditions are represented within it. The valley in this latitude is contracted somewhat, so that its width is greater both to the north and to the south than here.

South of Tuolumne River and east of the San Joaquin, the canals of the Turlock irrigation district supply gravity water to a large part of the valley; and north of the Tuolumne the canals of the Modesto district supply the west-central part of the county from a point about 8 miles east of Modesto to San Joaquin River. West of the San Joaquin the lower line of the San Joaquin and Kings River canal system extends to the vicinity of Crows Landing. Under these canal systems much alfalfa is raised, dairying is an important and growing industry, and there is an increasing acreage devoted to fruit raising and diversified farming. Outside of the irrigated district the greater part of the valley lands are in grain, both wheat and barley being raised, although here, as in other parts of the Great Valley, the production is less than formerly. Along the San Joaquin the flooded bottoms and the neighboring alkali lands are used for grazing.

Less use is made of underground waters in this county than in any part of the valley. The rainfall is sufficient, so that grain raising has been successful in the past, and irrigation, therefore, has not been absolutely necessary in order that the valley lands might be utilized, and the pressure for irrigation therefore has not been as intense as in the more strictly arid sections farther south. Furthermore, the surface supply is more nearly adequate than in many of the counties, and the limits of productivity through the use of the cheap gravity waters have not been reached, because the Turlock and Modesto districts are not yet fully developed. The needs that result from a combination of such complete aridity that crop production is impossible without irrigation and full utilization of all surface waters that are available, are not as yet operative in Stanislaus County, and there has not yet been an influx of the type of settler who is content to develop small farm units intensively in the way that is resulting in such successful use of small pumping plants as prevails about Stockton and Lodi.

FLOWING WELLS.

The Survey has records of only 5 flowing wells in the county. These are near the southern boundary, and most of them are west of San Joaquin River. Only one, that on the McDermott estate, northeast of Newman, is used for irrigation. The others furnish supplies for stock. The water from all of these wells contains an excess of saline matter in solution, so that it must be used with care.

Because of the meager development, the limits of the area within which flowing waters are to be expected can not be determined with certainty. Nor are these limits of as much importance here as farther south in the valley, because the flowing wells will yield rather meagerly, their waters will be of poor quality generally, and the flowing-well area will be confined to a zone of low land along the axis of the valley, much of which is subject to overflow and some of which is alkaline.

The settlers along the west side—owners of fertile, alkali-free soils, capable of immense production if water could be applied to them, but practically limited under present conditions to dry crops—are as a matter of course deeply interested in the possibility of securing irrigation water from any source. The streams that flow from the west-side hills toward the valley are wet-weather streams of slight flow and can not be considered as sources of irrigation water.

The San Joaquin and Kings River canal system may be capable of slight extension when irrigation practice on the lands under it improves; but at best it can serve only a small additional acreage. It is probable that pumping systems will eventually be installed to lift water directly from the San Joaquin to apply to those west-side lands that are within 40 or 50 feet of the low-water level in the river. Pumping plants may also be installed in the lower west-side lands to pump ground waters, but the lift will be nearly as great as from the river and the water will be of inferior quality, since all of the west-side ground waters contain notable quantities of salts and some of them approach the limit of usability for irrigation.

PUMPING PLANTS.

Pumping plants for irrigation are practically unknown in this county, but one or two being in operation. They are used, however, to supply the stations of the Pacific Coast Oil Company, the railroads, and the domestic supply for the city of Modesto. Ground waters are accessible with moderate lifts throughout the west half of the east slope of the valley, and as irrigation progresses under the gravity systems and the water plane rises, it will become increasingly desirable as a means of drainage as well as a source of auxiliary or independent gravity waters. That intensive cultivation and careful methods will make it as practicable here as it is elsewhere in the valley, scarcely needs affirmation.

SAN JOAQUIN COUNTY.

GENERAL CONDITIONS.

San Joaquin County is, with the exception of small areas in Alameda and Contra Costa, the northernmost of those counties whose valley lands belong to the southern division of the great central lowland of California. Because of its latitude and its position near the gateway that opens to the Pacific, it differs greatly climatically from the southern counties of the valley. Its temperatures are not as high and do not fluctuate through as wide a range (monthly averages vary from 46.5° in January to 72.5° in July and August), its rainfall is greater, amounting to about 15.5 inches, and its percentage of foggy days exceeds that of Kern, Tulare, and other of the southern counties. Furthermore, situated as it is along the lower San Joaquin, it includes a tidal section of that stream and a large area that is subject to inundation when the Sacramento is in flood, and a still larger section subject to overflow when floods in the San Joaquin and its tributaries occur at the same time as those of the Sacramento. The county, therefore, includes a part of that Central California area, whose problems of reclamation, drainage, and navigation involve in so complete and fascinating a way all of the phases of hydraulic engineering. The rivers must be improved and controlled for navigation purposes, the lowlands must be protected from floods and drained, while the higher bordering parts of the valley lands, too dry to produce the more valuable crops although suited to grain raising, require irrigation for their fullest development. This threefold problem belongs typically to the Sacramento Valley, but it requires solution also in that of the lower San Joaquin.

The Stanislaus Water Company takes its supply of water from the Stanislaus near Knights Ferry and irrigates an area of several thousand acres along the southern border of the county in the Escalon and Manteca districts. In the Lodi and Stockton districts the systems of the Stockton and Mokelumne Irrigating Company and the Woodbridge Canal and Irrigation Company supply surface waters to limited areas. Within the island district, west and north of Stockton, where reclamation has been accomplished by the construction of protective levees, water is sometimes admitted within the dikes during high-water periods in the streams for irrigation purposes, but as subirrigation is effectual throughout the greater part of these areas, surface irrigation is rarely necessary. The higher lands of the valley slopes, both along the east and west sides, are devoted to grain raising, as some of them have been for almost half a century. No water is applied to them. There is no uniformity as to practice among the vineyardists, some of them irrigating their vines, others preferring that they be not irrigated.

FLOWING WELLS.

San Joaquin County includes the northern portion of the great central artesian zone of the valley, but as this zone is less important in its northern part, both because of the inferior yield of wells there and because of the greater proportion of water of poor quality obtained from them, there has been relatively little development for irrigation purposes or domestic supply. Twenty-nine records have been obtained and these are believed to include all of the flowing wells in the country districts and nearly all of those in the city of Stockton. Only six of these supply water that is suitable for irrigating purposes and the yield of these is small. By far the greater number of the flowing wells have been drilled for the gas they yield. In all such wells, the water with which the gas occurs is saline and is allowed to waste, since it is not usable for drinking purposes or for irrigation.

The few artesian wells that furnish water of good quality not only yield small supplies but are expensive because of their considerable depth. Those of which records are available are from 975 to 1,200 feet deep. Wells of lesser depths do not yield flows, and those with greater depths, at least in the Stockton neighborhood, yield saline waters and gas. Farther west than Stockton, nearer the axis of the valley, it is probable that the water, even from shallow wells, would be alkaline. It will be realized that under these conditions flowing wells are not of value for irrigation purposes in the county, despite the rather large area over which flows may be obtained.

PUMPING PLANTS.

During the last few years irrigation by the use of pumped waters has become an important factor in the development of the east side of San Joaquin County. Around Lathrop and French Colony, in the district east of Stockton and in the country about Lodi, a large number of plants have been installed and new wells are being sunk and new plants put in operation constantly.

This development is of a most promising type. Most of the plants are small and the acreage irrigated by each is limited. This means small holdings, intensive cultivation, and eventually relatively dense settlement. The average recorded horsepower of 193 plants is only 6.2. Of the 193 plants 138 develop from 2 to 8 horsepower, while 42 are equipped with engines developing from 10 to 15 horsepower. One hundred and eighty-seven gas engines are in use, thirteen plants use motors, and two are operated by steam.

One hundred and thirty-seven owners of plants report a total of 1,455 acres, an average of only 10.6 acres each. The cost of 106 of

the plants is reported by the owners as \$64,983, an average cost of \$613 each. These facts indicate the small scale and individualistic character of the development.

The power companies charge a uniform rate of $3\frac{1}{2}$ cents per horsepower per hour. This is higher than the fuel charge in the gas plants, the reported average in 12 plants for the summer of 1906 being 1.45 cents per horsepower per hour, but labor and installation, both of which are heavier charges in the gas plants, tend to equalize the difference. Water as developed in these small plants seems to cost the users from \$1.50 to as much as \$3 or \$4 per acre-foot.

Generally water is delivered from the pumping plants to the acreage served through earth ditches, and where the soil is sandy and porous this method results in much waste.

The pumping-plant wells are comparatively shallow, and hence are very much cheaper than the deep wells necessary to secure artesian flows. The average depth of somewhat more than 100 wells, taken at random from the records, is about 80 feet. Another group of 20 wells average only 40 feet in depth. These latter wells are equipped with small pumping plants, developing an average of 5 horsepower each, and the water which they yield is ample.

The wells are particularly cheap because it has been found that in many parts of the area it is not necessary to case them, or at least they must be cased only to slight depths. Twelve pumping-plant wells are reported as without any casing; 24 others were only partially cased, the pipe in these varying in length from a few joints to three-fourths or seven-eighths of the entire depth of the well.

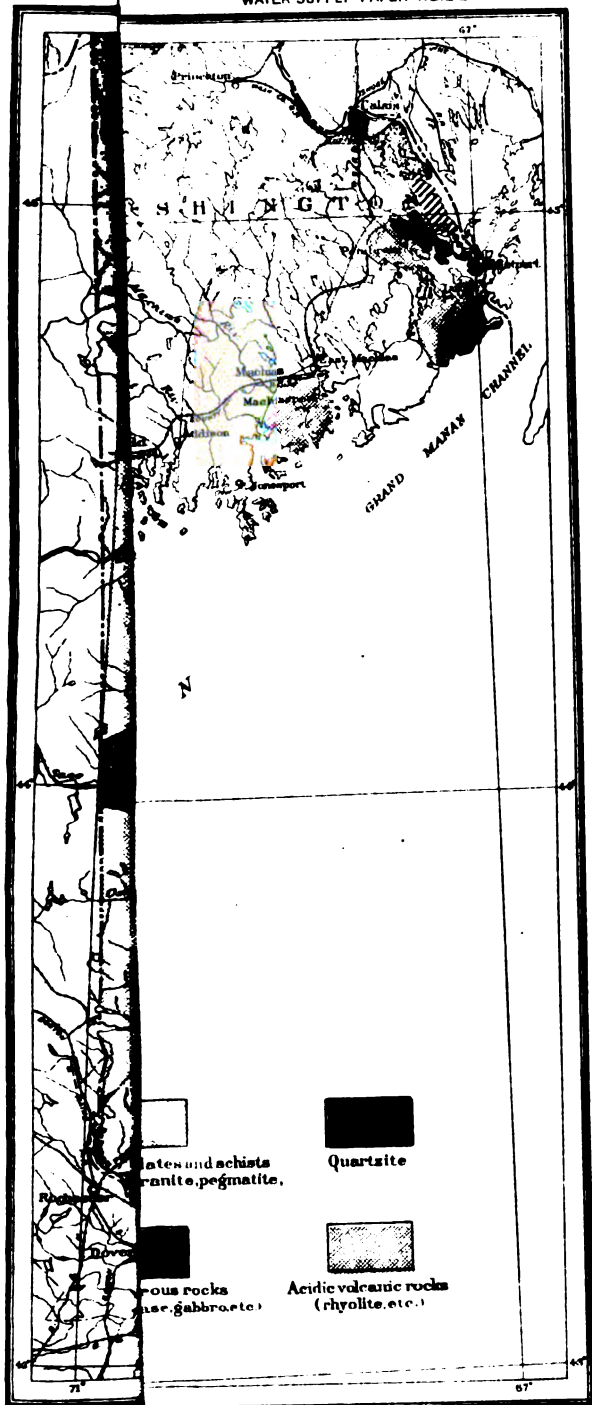
The windmill has been an important factor in the past in irrigation in the Stockton district, and although it is being rapidly superseded by the small pumping plant, it is still extensively used, especially in the vegetable garden and fruit districts east and northeast of Stockton. Its chief disadvantage, of course, is the uncertainty of the wind. It is not unusual to see a well equipped both with a small gas engine and a large windmill, the engine being used when the wind fails. The wheels used are of wood and of local manufacture, from 18 to 22 feet in diameter, and cost complete with the tower from \$175 to \$200.

Much of the gardening and fruit for the San Francisco market is in the hands of Italian immigrants, who, after giving the windmill a thorough trial, are now abandoning it in favor of the more reliable small gas engine.

Irrigation by pumping, of the general type practiced about Stockton and Lodi, could be extended with great advantage throughout a large acreage, now without water, between the Mokelumne and Tejon Pass, but to be practiced successfully it will require a different spirit from that which as yet largely dominates the West. The promoting

and speculative spirit, the desire to get rich overnight, to control large holdings, and to avoid personal labor, will have to be superseded by a willingness to be satisfied with sure but moderate returns, to be content with small farm units, and to attain personal independence through individual effort. It is to be hoped that the American citizen of the generations to come will prove willing to accept these conditions and that in the future dependence need not be placed upon our adopted citizens for detailed development of this desirable type.

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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

WATER-SUPPLY PAPER 223

UNDERGROUND WATERS OF SOUTHERN MAINE

BY

FREDERICK G. CLAPP

WITH

RECORDS OF DEEP WELLS

BY

W. S. BAYLEY



WASHINGTON
GOVERNMENT PRINTING OFFICE
1909

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UNDERGROUND WATERS OF SOUTHERN MAINE.

By **FREDERICK G. CLAPP.**

INTRODUCTION.

LOCATION AND AREA.

The area covered by this report is roughly triangular and includes all of southern Maine, from the coast northward beyond Calais, Oldtown, Skowhegan, and Rangeley. Its northern boundary may be said to follow very nearly the line of the forty-fifth parallel, but a few towns situated a short distance north of the line have, for special reasons, been included in the discussion. Fig. 1 shows the relation of this area to the rest of the State. Its greatest extent east and west is 210 miles, and north and south, along the New Hampshire line, about 130 miles.

CHARACTER OF REPORT.

It was originally intended that the entire State should be covered by a single report, but field investigations showed that the subject was much broader than at first supposed. Although there are large areas which are settled either sparsely or not at all, where little information regarding underground waters can be obtained and little is yet needed, there are wide areas where the water problem is very important and extensive well drilling is going on. This is true of the summer-resort regions, and of the great farming region covering the larger part of Aroostook County. It was found impracticable, therefore, to include the entire State in a single report, and it was decided to confine this report to the region south of the forty-fifth parallel, and to cover the northern part of the State by a special investigation.^a

In order to meet the needs of all classes of readers the report is so subdivided as first to describe the general water resources of the region, the dependence of quality and quantity on character of rocks,

^a The report for the northern part of the State is in preparation.

the location and type of wells, etc., and then to discuss in detail the conditions in the various counties, for the benefit of persons needing

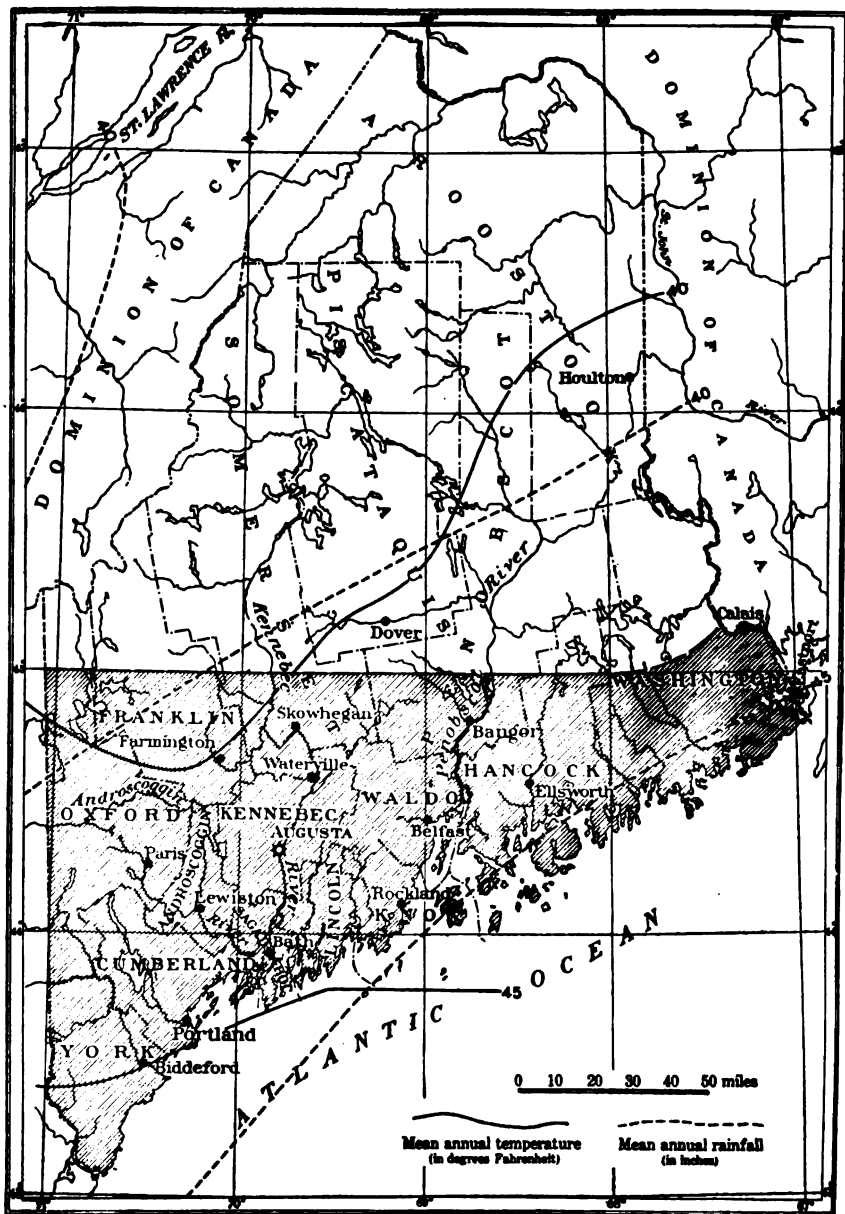


FIG. 1.—Index map showing area described in this report; also mean annual temperature and mean annual rainfall for Maine.

local information. The table of deep wells, compiled by Professor Bayley, is appended for the benefit of persons desiring to drill wells.

NEED OF INVESTIGATION.

The available knowledge regarding the underground-water resources of Maine has heretofore been rather scant. Surface waters and open wells have been largely used, and where deep wells have been resorted to they have been drilled at random, without a scientific forecast of the amount or the quality of the water available at that particular point or with that particular type of well. People are now beginning to realize that well drilling, like other prospecting, in order to be economical to the owners and drillers, must be conducted in accordance with certain scientific rules, which point out the source, depth, amount, and quality of water in different types of rock and different localities. Hence a comprehensive investigation is necessary throughout the State.

The Geological Survey frequently gets requests for information regarding the occurrence or the quality of water in certain towns. In sections of the State where water is scarce, as on the islands and along the coast, especially in the summer-resort region, it is necessary that people should be informed whether it is possible to obtain water by drilling, and if so, at what depth it may be procured. Many towns in the State are searching for a public supply, and some towns have poor supplies and wish to improve them. This report aims to help in solving such problems. Another object in view is the securing of proper well construction. In some parts of the State and by some drillers the most modern methods of drilling and casing wells are used; elsewhere, however, and by other drillers, wells are improperly constructed and some are dangerous to the public health. A comparison of the various methods of construction ought to teach valuable lessons.

SOURCES OF INFORMATION.

Previous literature.—The first lists of deep wells and springs in Maine were published in 1904.^a A few additional wells were recorded in 1905.^b A brief account of the underground-water conditions, with lists of important springs, was also given in 1905,^c and in the same year the conditions in the Kittery-York district, in the extreme southwest corner of the State, were described.^d A short paper in the same report described a possible water supply from glacial gravels in the vicinity of Augusta.^e

Correspondence.—Much of the data contained in the first three of the above-mentioned reports was gathered by correspondence, but whenever records could subsequently be obtained in the field they

^a Bayley, W. S., Water-Supply Paper U. S. Geol. Survey No. 102, pp. 27-47.

^b Darton N. H., Water-Supply Paper U. S. Geol. Survey No. 149, p. 63.

^c Bayley, W. S., Water-Supply Paper U. S. Geol. Survey No. 114, pp. 41-56.

^d Smith, G. O., Water-Supply Paper U. S. Geol. Survey No. 145, pp. 120-128.

^e Smith, G. O., op. cit., pp. 156-160.

were added to the list. In obtaining records blanks were sent out containing questions to be answered by well owners or drillers. Considerable information regarding mineral springs has also been obtained by correspondence since the field work was finished.

Field work.—The field work for the present report was done during four months in the summer of 1906. The author was assisted by George C. Matson and B. L. Johnson, and many of the data here given are taken from their notes. It was impossible to visit every town, but all the larger places and those localities which present special problems were visited, and the conditions of occurrence and the quality of well and spring waters were investigated. All public water supplies from underground sources were seen, the important mineral springs were visited, and interviews were held with professional well drillers in order to get authoritative information regarding conditions of drilling.

ACKNOWLEDGMENTS.

The accuracy and completeness of this report have necessarily been dependent to a considerable extent upon the work of other persons besides the author. George C. Matson and B. L. Johnson have assisted in both field and office work. A number of years ago Prof. W. S. Bayley was requested to prepare a table of deep-well records of Maine, which were obtained by correspondence extending over a considerable period of time. These records as submitted by Professor Bayley contained some additional descriptive matter, which has been added to this report. The table has been revised and brought up to September, 1906, and appears on pages 242–259. Several pages of the report, bearing on occurrence and methods of obtaining water in general, have been compiled from notes furnished by M. L. Fuller. Some of the geologic descriptions are taken from reports by George Otis Smith and E. S. Bastin. A large number of the chemical analyses were made by Prof. F. C. Robinson, the samples being collected by A. C. Robinson. Analyses made by other chemists which were not originally expressed according to the uniform system adopted by the United States Geological Survey for use in its publications were submitted to R. B. Dole, of the Survey, for recomputation. C. E. Shute, C. H. Scribner, Fred Foster, Lester Maxwell, and the Poland Brothers, all prominent well drillers, have taken an interest in the investigation and furnished much valuable information. Other drillers have assisted in gathering data.

A comprehensive report on water supplies is manifestly impossible without the assistance of persons in the region which is to be benefited by the report, and in compiling the facts here presented it has been necessary to interview hundreds of residents of the State and to

correspond with several hundred more. To all who have assisted, directly or indirectly, the author wishes to express his thanks. In furnishing information to the Survey they have performed a valuable public service.

RESULTS OF INVESTIGATION.

The investigations thus far conducted in Maine have shown that there is an abundance of water beneath the surface in granite, slate, and other rocks, but as the water occurs in crevices which are not regularly distributed through the rocks, the amount which will be found at any given location or depth is uncertain and can never be definitely predicted. Water in the rocks is usually of good quality, but in some districts it has a large mineral content. Water in surface deposits is generally abundant except in dry weather, but the quality can not be depended upon. It has been found that drilled wells are the most satisfactory and that dug wells and combinations of dug and drilled wells are to be avoided, especially in villages. Most of the commercial mineral springs of the State are safely situated, and their water is of excellent quality. Only a few springs were seen which should be condemned. The public water supplies are mostly satisfactory, but in a few of them, owned by private parties or corporations, the water is badly polluted. In such cases the abandonment of present sources is recommended. No special investigation of surface supplies was made, but it is known that some of these are not satisfactory and that changes should be made.

SETTLEMENT AND DEVELOPMENT AS RELATED TO WATER UTILIZATION.

With the exception of Florida, Maine is the least densely populated of all the Eastern States (23.2 per square mile). Because of this fact and the abundance of lakes and streams, its people have until recently felt little necessity for seeking sources of water supply below the surface. Consequently the underground waters of the State have been, on the whole, but slightly utilized, except in certain restricted areas, where for one reason or another the surface waters have not been suitable for domestic or manufacturing purposes.

Until very recently the rivers and lakes have afforded excellent water for nearly all purposes. With the increase in the number of factories established on the main waterways the rivers have become less and less valuable as sources of water supply, partly because of the waste products poured into them from the factories and partly because of the increased amount of sewage which they must carry in consequence of the growth of the manufacturing communities on their banks.

The drift of the population toward centers is well shown by the census of 1900. The number of cities and villages separately enumerated in this year was 43, as against 25 in 1890, and their population was 258,431, as against 184,821 in 1890, or 37.2 per cent of the total population in 1900, as against 28 per cent in 1890.

The natural result of the two tendencies above mentioned has been pollution of the principal watercourses, with the consequence that communities drawing their public supplies from streams are beginning to complain of the quality of the water furnished them and are turning toward lakes or wells for relief.

Along the coast, where the larger rivers are tidal, communities are dependent on lakes and small brooks for their public supplies. On the islands the principal sources of drinkable water are springs and drilled wells, but as there are only a few island settlements of any considerable size the question of large public supplies for the islands is not of great moment. The rapid growth of summer-resort communities has brought about a demand for information regarding deep-well prospects in such places. In the interior of the State many villages that are not situated near large lakes or spring-fed brooks have taken advantage of the good springs and have obtained through pipes a supply of spring water.

SURFACE FEATURES.

GENERAL STATEMENT.

Water is found in some amount in all formations below the earth's surface from the loosest and most porous sands and gravels to the hardest slate and granite. The amount varies from the merest trace chemically combined in the molecules of the rocks to immense reservoirs which supply wells flowing hundreds of gallons per minute. Some waters are so pure that a refined chemical analysis shows only minute traces of organic and mineral matter; others are so heavily charged with minerals or other impurities as to be unsuitable for use.

The slope of the surface at any point is one factor determining the amount of water absorbed by the ground. The direction and amount of slope also determine the form of the water table—that is, of the upper limit of saturation. Except where the surface is flat the water table is generally not parallel with the surface; it is almost invariably farthest from the surface on the summits of hills and mountains and nearest to it in valleys and along the coast, reaching the surface in swamps and along rivers, lakes, and beaches. The surface of the water table is always in motion, its higher portions flowing toward the lowest outlets along rivers or the sea. This direction of flow explains why fresh water is usually found when a well is dug in a sandy beach.

PRINCIPAL SURFACE FEATURES OF SOUTHERN MAINE.

Altitudes in Maine range from sea level to about 5,200 feet, the highest summit being Mount Katahdin. In some of the central portions of the State the land is very mountainous, but in parts of Aroostook County it is nearly flat. The surface may be said to consist essentially of an extensive southward-facing slope draining directly into the Atlantic Ocean and a smaller northward-facing slope draining into St. John River. The latter area is a great plain with numerous swamps, above which rise a few hills. The surface of the southern slope is much more broken. Its western portion is crossed by ridges of low mountains trending east or northeast, some of which rise several thousand feet above the surrounding country. These are separated by wide areas of plain, on which are many small hills and ridges. Near the coast much of the surface is rough. Rocky ridges and low, bare hills stretch from the shore line some miles inland, but few of these hills are lofty and the valleys between them are not deep. The coast is in most places rocky, but at some points there are sandy beaches, several of which are among the finest in the country.

DRAINAGE.

GENERAL DESCRIPTION.

No other tract of country of the same extent on the continent is so well watered as Maine. The State contains five principal lake systems—that is, large lakes connected by rivers and discharging into main channels which convey their accumulated waters to the ocean.

These systems are, beginning on the western boundary, (1) the Umbagog-Rangely series, with an area of 90 or more square miles, drained by Androscoggin River; (2) the Moosehead series, forming the headwaters of Kennebec River, the main lake of which is 120 square miles in area and is the largest inland body of water in New England; (3) the Penobscot series, consisting of Chesuncook and its surrounding lakes on the West Branch of the Penobscot; Alleguash, Chamberlain, and others on the East Branch, and the Sebobeis and others connected with it still farther east but flowing into the East Branch of the Penobscot; (4) the Schoodic Lakes, in the southeastern part of the State, drained by St. Croix River; and (5) the many lakes forming the headwaters of St. John River and its tributaries. There are many other lakes in every county, which, though of small area, in the aggregate hold an immense amount of storage water and add much to the importance of the lake systems of the State. The total number of lakes, not including small ponds tributary to the rivers, is 1,620, and their total area 2,300 square miles, making one lake to each 20 square miles of territory and one square mile of lake surface to each 14.3 square miles of land surface.^a

DETAILED DESCRIPTIONS.

The main drainage systems within the area covered by this report are described below, the descriptions being taken from the paper by Pressey just cited.

^a Pressey, H. A., *Water powers of the State of Maine: Water-Supply Paper U. S. Geol. Survey No. 69, 1902, p. 16.*

Saco River system.—Saco River rises in the White Mountain region of New Hampshire at an elevation of about 1,900 feet above the sea, and has a general southeasterly course to the Atlantic Ocean. The greatest length of the basin from Mount Washington to the sea is about 75 miles; the greatest width about 30 miles. The total drainage area is 1,750 square miles, about equally divided between Maine and New Hampshire. The general elevation of the basin is greater than that of any of the larger streams of Maine except the Androscoggin. The headwaters are in one of the highest and roughest mountain regions in the eastern part of the United States, with steep, wooded slopes and narrow river valleys and with heavy falls to the mountain streams. The mountains grow gradually lower, however, as the ocean is approached, becoming undulating hills in the central part of the basin and comparatively flat land near the sea. The northern part of the basin is still largely wooded, while in the southern part practically all of the forests have been cut, so that more than half the entire basin has been cleared.

Presumpscot River system.—This is one of the most interesting as well as one of the best water-power streams of its size in the United States. It is the outlet of Sebago Lake, which lies about 17 miles northwest of Portland. The lake is fed by Crooked River, a stream heading 35 miles farther north and within 3 miles of the Androscoggin. The area of the lake is 50 square miles, the area of its drainage basin at the outlet of the lake is 470 square miles, and the total drainage area of the river at its mouth is 700 square miles. The northern part of the basin is mountainous and wooded, while the southern part is moderately hilly and cleared of trees.

Androscoggin River system.—The Androscoggin River is formed by the junction of Magalloway River and the outlet of the Umbagog-Rangeley lakes near the Maine-New Hampshire boundary line. For about 35 miles it flows southward into the State of New Hampshire, then turns abruptly to the east and flows into the State of Maine, then turns to the south and joins the Kennebec in Merrymeeting Bay. The total drainage area above Brunswick, where is the last fall, is 3,700 square miles, about 80 per cent of which is in Maine. The greatest length of the basin is 110 miles, the greatest width 70 miles, while the river itself measures about 200 miles in length from the sources of Magalloway River to the coast. * * * The lower part of the basin is hilly and moderately wooded, while the upper two-thirds is very broken and mountainous and heavily timbered.

Kennebec River system.—The Kennebec River basin lies between those of the Androscoggin and the Penobscot, and extends from the Canada line to the ocean. The basin measures 150 miles in length and varies in width from 50 to 80 miles in the main portion, embracing a total area of 6,330 square miles. Of this area 1,250 square miles are tributary to Moosehead Lake. The general elevation is less than that of the Androscoggin basin, though near the center of the area Saddleback, Abraham, and Bigelow mountains rise as isolated peaks to elevations higher than any [other] mountains in the State except Katahdin. The river rises in Moosehead Lake, though its headwaters are collected by * * * a number of small streams rising in the hilly forested areas lying to the east and west of that lake. Near Moosehead the hills and highlands are well back from the lake, leaving a great open plain. The northern part of the drainage basin is broken by offsets from the White Mountains. Nearly the whole of the upper portion of the drainage area is forest covered and in its original wild state.

Penobscot River system.—The Penobscot has the largest drainage basin of all the rivers in Maine, comprising about 8,500 square miles, or more than one-quarter of the entire State. Its greatest length from north to south is 160 miles, its greatest width 115 miles, all within the State. Eight hundred square miles of the basin discharge their waters into the main river below its lowest water power at Bangor. The basin is at a lower elevation above the sea than the basins of the Kennebec and the Androscoggin, as would be expected from the general southeasterly slope of the country toward

the Atlantic Ocean. The northern portion, however, is rather elevated, having a mean height of about 1,000 feet. The highest portion of the basin is at the headwaters of the main river, where the elevation is from 1,600 to 2,000 feet. Taken as a whole, the basin is rather uniform in its topographic features. Hills and low mountains stretch from near the sea above Bangor; farther north is an undulating plain, while to the west the surface becomes more broken and greatly diversified by hills, detached peaks, lakes, ponds, and swamps. At the south the basin merges into that of Kennebec, and at the north into that of the Alleghuash. * * * A large part of the basin is what is known as "wild land," being heavily timbered and known only to the lumberman and the sportsman.

St. Croix River system.—St. Croix River is formed by two branches, known as the Upper St. Croix or Chiputneticook River, the outlet of the Schoodic Lakes, and Kennebasis River, the outlet of the western lakes of the area, known as the Kennebasis Lakes. The Upper St. Croix, with its tributary lakes, forms nearly half of the eastern boundary of Maine, separating that State from New Brunswick. The total drainage area of the main stream is about 1,630 square miles, of which 960 square miles are tributary to the great reservoir systems controlled by dams at Vanceboro and Princeton. The length of the stream from the headwaters to the mouth is 100 miles. The basin is, in general, lower than that of any of the larger streams of the State flowing into the Atlantic, its headwaters having an elevation of about 540 feet. * * * The lake system of the St. Croix is the largest in the State in proportion to the drainage basin, except that of the Presumpscot. * * * The lake system of the Upper St. Croix comprises approximately 50 square miles of lake surface, and that of the West Branch 70 square miles, considering only the principal lakes and ponds. Indeed, above Vanceboro and Princeton each branch of the river is simply a succession of lakes to almost the extreme headwaters. The total lake surface of the St. Croix is estimated as not less than 150 square miles, or nearly one-tenth of the total drainage area.

Coastal streams.—Between the St. Croix and the Penobscot are Dennys, East Machias, West Machias, Narraguagus, Union, and other rivers, and between the Penobscot and the Kennebec are the St. George, the Pemaquan, and others, while at the southwestern extremity are the Mousam and the Piscataqua, the latter forming a part of the western boundary of the State. These streams are all comparatively small, but their importance is greater than their size would indicate, from the fact that they are in a more thickly populated part of the State and are nearer the coast, where transportation facilities are much better than in the interior, and that they have considerable fall and regular flow, due to the lakes and ponds tributary to them.

RELATION OF CLIMATE TO UNDERGROUND-WATER CONDITIONS.

The climate of Maine is healthful. Although the winters are long and severe the summers are pleasant and warm. The mean annual temperature ranges from 37° at Fort Kent to 46° at Portland.^a

The mean annual precipitation ranges from 35.3 inches at Fairfield to 52 inches at Mayfield, Somerset County, there being 11 climatological stations in the State, as shown by the accompanying table. Fig. 1 shows the isothermal and isobaric lines for the State.

^a Boardman, S. L., Special Rept. U. S. Dept. Agr. No. 4 1884, pp. 16-20. Henry, A. J., Bull. Q. U. S. Weather Bur., 1906, pp. 122-134.

Climate and rain/fall statistics at stations in southern Maine. a

	Fairfield.	Mayfield.	Orono.	Rumford Falls.	Eastport.	North Bridgton.	Lewiston.	Gardiner.	Bar Harbor.	Cornish.	Portland.
PRECIPITATION.											
Spring.....	8.4	12.2	10.1	10.8	11.3	12.9	11.6	11.5	12.2	11.4	10.6
Summer.....	9.1	16.8	10.2	11.5	10.0	11.8	10.6	9.4	9.3	12.6	10.2
Autumn.....	8.9	11.8	10.4	9.7	11.1	11.2	11.5	10.4	12.3	12.2	11.0
Winter.....	8.9	11.2	11.9	10.1	11.0	11.7	12.5	11.7	14.5	11.7	11.0
Annual.....	35.3	52.0	42.6	42.1	43.4	47.6	46.2	43.0	48.9	47.9	42.8
TEMPERATURE.											
Maximum.....	97	96	100	101	93	100	100	101	96	97	97
Mean maximum.....	53	54	53	52	49	55	54	56	53	52	53
Minimum.....	-37	-23	-36	-29	-21	-26	-24	-30	-17	-19	-17
Mean minimum.....	32	32	33	33	35	34	34	35	35	37	38
Mean annual.....	43	42	43	43	42	44	44	45	44	44	46
Average number of days over 90°.....	2	2	2	3	1	3	5	8	1	3	3
Average number of days under 32°.....	172	168	166	151	133	153	160	152	151	140	127
FROST (AVERAGE).											
Latest killing frost in spring.....	May 13	May 17	May 11	May 15	Apr. 28	May 15	May 5	May 6	May 18	May 23	Apr. 14
Earliest killing frost in autumn.....	Sept. 24	Sept. 22	Sept. 24	Sept. 20	Oct. 12	Sept. 15	Oct. 2	Oct. 1	Oct. 12	Sept. 12	Oct. 18

a Henry, A. J., Bull. Q., U. S. Weather Bureau, 1906, p. 714.

As a rule, the rainfall is fairly well distributed throughout the year, some of it occurring in every season. Thus a large part of the precipitation occurs when the ground is unfrozen, and much of the rain penetrates the ground and goes to increase the underground water supply.

The winters often begin in November, but the climax of the season is not reached till February, and the winter generally ends in April. The summers are, as a rule, short, generally beginning abruptly in June. Fair weather predominates. In July and August there are frequently several successive days of muggy weather, followed by cooler spells, generally with east winds, during which the contrast in temperature is striking. The coldest place in winter is Fort Kent, and the coolest place in summer is probably Eastport, which has a summer mean temperature of 59°. Summer generally terminates gradually in the latter part of September.

UNDERGROUND WATERS.

SOURCE OF UNDERGROUND WATERS.

Rainfall.—Practically all the water utilized for domestic purposes is supplied by rain. The 35 to 52 inches of rainfall disappears from the surface principally in three ways—(1) by evaporation; (2) by run-off through the streams; and (3) by absorption into the rocks and unconsolidated deposits. It is with the last-mentioned portion of the rainfall that an underground-water report is concerned.

Evaporation.—Evaporation, although far less conspicuous than the other methods of removal of the water from the surface, is nevertheless one of the most important. The quantity thus removed commonly amounts to one-half or more of the total water falling as rain. This water never enters the ground, and therefore does not become a source of supply for domestic or other purposes.

Run-off.—The run-off includes the water that flows over the surface into streams and lakes and is carried seaward through definite channels. The quantity disposed of in this way is dependent partly on evaporation and partly on the nature of the materials on which the rain falls. The amount of run-off or discharge in the drainage areas of the two principal river systems of the State is as follows: Kennebec, 22.4 inches; Androscoggin, 24.2 inches.

Absorption.—The rainfall that is not removed by evaporation or by run-off into surface streams is absorbed by the soil or rocks with which it comes in contact, either directly or after being gathered into streams. In the first case the rain falls on the surface of the rocks or on the loose unconsolidated deposits lying upon them, and is either soaked into their pores or passes into the fissures and cavities which may be present in the harder materials. In the second case

the water flows into the streams, and from these it may seep into the rocks in which their channels lie, but this seldom occurs in Maine. In either case the unconsolidated materials lying upon the rock surface are saturated to a certain level, and the rocks upon which they lie are in this way kept in contact with water, which is continually being absorbed.

When water enters sands and gravels the direction of movement in moderately moist regions like southern Maine is generally toward the river rather than away from it, but in arid regions, where the rainfall is slight, waters are often absorbed by the gravels in the beds of streams which have come from regions of greater rainfall.

MODE OF OCCURRENCE.

Water occurring in sands, gravels, and other surface deposits is generally held in the pores, or spaces between the pebbles or smaller particles. In certain types of solid rocks, as some sandstones, conglomerates, and very porous limestones, water occurs in the same way, saturating the entire rock below the level of the water table. Most rocks found in Maine, however, are so hard, compact, and close grained that the amount of water contained in the pores is very small. In such rocks practically all the water is held in various forms of crevices, cavities, and fissures. In the slates and argillaceous schists which underlie a large part of the area under discussion, considerable water is held in the bedding and cleavage planes. In granite, gneiss, slate, schist, and most other hard rocks the largest amounts are contained in joint cracks—fissures which cut the rocks in various directions. Where rocks have been faulted—that is, where one wall of a fissure has been moved up or down or horizontally with reference to the other wall—lines of springs sometimes follow the fault where it cuts the surface. In limestones large amounts of water occur in solution cavities which have been dissolved by slow water percolation.

AMOUNT OF GROUND WATER.

General statement.—The amount of water held in the rocks or other materials composing the earth varies greatly, owing to many causes. The amount absorbed depends on the porosity of the material, the slope of the surface, and the size and abundance of joint cracks, fissures, and cavities. The amount of water in drift or surface materials is dependent to some extent on the nature of the underlying rock, and the amount which finds its way into the solid rocks is dependent on the thickness of the overlying surface deposits.

Amount of absorption.—The amount of water absorbed is dependent chiefly on the nature of the materials. The more porous beds of sand and gravel that occur as drift deposits along stream valleys, lake

shores, and the coast absorb very large amounts. Next to these unconsolidated deposits, the rocks which present the conditions most favorable for direct absorption are sandstones and certain porous limestones. The direct absorption by granites, slates, and other massive rocks is very slight. In a general way porosity is determined by the amount of water which the rock is capable of absorbing. A cubic foot of sand will absorb on an average about 10 quarts of water, and certain porous sandstones will absorb 2 to 6 quarts.

Upper and lower limits.—In general it is necessary to dig only a few feet to reach a zone saturated with water. The upper limit of this zone is known as the water table, and the water saturating the materials is known as ground water. The general relations of water table and ground water are shown in fig. 2. The depth to the water

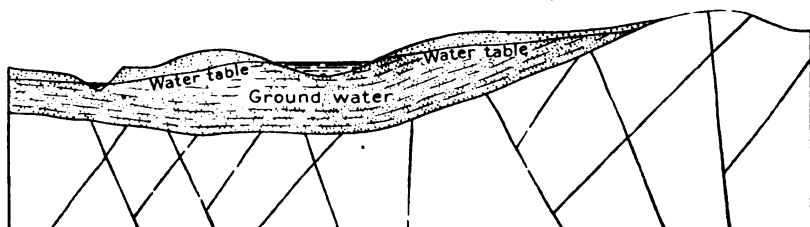


FIG. 2.—Diagram showing relation of ground water and water table to outcrop and bed rock.

table is dependent principally on the amount of precipitation, being least in regions of much rainfall and greatest in arid regions. While there is no definite lower limit to the penetration of water, it is probable that little surface water penetrates more than 3 miles below the surface, and most of the pores and crevices in rocks are closed below the depth of a few hundred feet.

Total amount of ground water.—The total amount of water contained in the earth's crust has been estimated by different writers with widely different results. The most recent estimate is given by Fuller,^a who concludes that the total amount of free water in the earth's crust would be equivalent to a uniform sheet over the entire surface of the earth with a depth of about 100 feet. This is but a small fraction of the estimate made by other writers.

ULTIMATE DISPOSITION OF GROUND WATER.

The water held in the rocks of the earth's crust disappears in a number of ways. A small portion enters into the chemical composition of the rocks. Small amounts are absorbed by forests and other vegetation. Some of the water reaches the air through capillarity and is evaporated. The largest amounts reach the surface by

^a Fuller, M. L., Total amount of free water in the earth's crust: Water Supply Paper U. S. Geol. Survey No. 160, 1906, pp. 59-72.

hillside springs and through seepage to neighboring streams. In settled regions large amounts serve as contributions to wells. It is the two last-mentioned portions and the portion still remaining below ground with which we are concerned in this report.

TEMPERATURE OF UNDERGROUND WATERS.

In all wells there is a certain depth, which differs in different localities but is commonly from 50 to 60 feet below the surface, at which there is practically no variation in the temperature of the water from season to season or from year to year. The temperature at this depth is known as the normal temperature of the water for a given locality, and it agrees very closely with the mean annual temperature of the same locality.

In southern Maine the normal water temperature is 40° to 47° . Waters occurring nearer to the surface than the zone of uniform temperature vary in temperature according to season, being warmer than the normal in summer months and colder in winter months. Below the depth of normal temperature the temperature increases, owing to the internal heat of the earth, the average increase being about 1° in every 50 feet. A temperature higher than that which would be expected at a given depth may be due to the derivation of the water from a deep source, but as no thermal springs are known in Maine this cause is not believed to prevail. Where an abnormally high temperature is found in summer it is generally due to the mixture of surface water with the deep-well water, either by leakage along the casing or by penetration downward through joint cracks.

Many determinations of deep-well temperatures have been made throughout Maine, and are found to vary from 45° to 54° , being commonly somewhat higher than the normal. The most common temperature was 47° . In this State the temperature seems to hold no definite relation to the depth of the well, as would be expected; the reason is supposed to be that water in most rock wells in Maine is derived from more than one vein, and the principal supply is not invariably at the bottom of the well. In any well not properly cased surface water may enter and raise the temperature above the normal. The true temperature of a well water can be found only by pumping several minutes before taking the measurement, to exhaust the water which has become either heated (in summer) or cooled (in winter) in the piping.

The temperature of a well water is frequently a factor of considerable importance to the users. In a number of pulp mills in Maine well waters are used for cooling acid. They are also used in creameries for cooling cream, and for ordinary drinking purposes it is more pleasant to have a cool water. Practically all rock waters in Maine are cool enough for drinking, but in some dug wells the water is warmer

than the average. Deep-well water whose temperature is higher than 50° is open to suspicion; it is probably in part surface water.

QUALITY OF UNDERGROUND WATERS.

General statement.—Rain water falling near the close of a storm, after the impurities have been dissolved out of the air, is very nearly pure H_2O . As it finds its way below the surface, however, into the soils and surface deposits it dissolves and holds in solution small quantities of organic and mineral matter. Normally in the country districts, where the ground water does not come into contact with polluting materials in its downward passage, it dissolves only a small amount of organic matter, but takes into solution some mineral matter. As the water moves downward still farther and enters the underlying solid rocks large quantities of mineral matter may be taken into solution. In Maine the quantity of mineral matter is seldom more than 200 to 500 parts per million, and this does not affect the safety of the water for drinking purposes. In towns, however, and in the vicinity of houses, barns, refuse heaps, privies, and cesspools, considerable amounts of polluting organic matter are dissolved by the ground water, and such water is dangerous for domestic supply.

Source of mineral matter.—Polluting organic matter always comes, directly or indirectly, from the surface. Mineral matter, however, may enter the water in a number of ways. In most parts of the State it is practically all dissolved from the rocks or other materials in which the water is found or through which it has passed. For this reason water in limestone and calcareous slate, the materials of which are easily soluble, contains large amounts of mineral matter, whereas water in such rocks as granite and ordinary clay slate contains less amounts. Certain mineral constituents, as nitrites, nitrates, and chlorine, are frequently derived from organic matter, and therefore their presence in abnormal quantities is an indication of pollution. In some wells on islands or near the ocean the amount of mineral matter is found to be very high, frequently running up to several thousand parts per million. Such proportions are sometimes due to a mixture of salt water which has entered from the sea.

Normal chlorine lines.—One of the best indications of the source of water, especially of surface water, is chlorine. This element, a constituent of common salt, is present in nearly all natural waters. Its original sources are certain mineral deposits and finely divided salt spray from the sea. This sea spray, which is of most importance as a source of chlorine in Maine, is carried inland with dust particles and precipitated with the rain. The chlorine decreases as waters farther and farther inland are tested, and hence it has been possible to make determinations and prepare a map giving lines of equal chlorine

which represent the normal percentages throughout the State.^a All salt found in water not derived from mineral deposits or from the sea comes from domestic drainage and indicates that the water either is at the present time polluted or was polluted and has since been purified. For surface waters the normal chlorine lines hold with great accuracy. For most underground waters, however, owing to the occasional presence of chlorine in rocks and to the frequent circulation of water to localities of different normal chlorine, the map is of little value, and should not be depended on except when considered together with other evidence.

WATER-BEARING ROCKS OF MAINE.

PRINCIPAL TYPES.

General statement.—All formations contain more or less water, which, as has been pointed out, occupies cavities or crevices in the rock or is held between the pores. The principal rocks in southern and eastern Maine are granites, gneiss, slate, schists, and surface volcanic rocks, with a few small areas of limestone, quartzite, and other rocks. Overlying these are usually surface deposits, consisting of sand, gravel, glacial till, and marine clays.

Relation to underground waters.—The amount and the nature of the water occurring at any locality are dependent on the kind of material in which it occurs. The distribution and character of water in various materials are summarized in the following table:

Summary of occurrence of water in rocks and surface deposits of southern Maine.

Material.	Distribution.	Water supply.
Granite	Irregularly distributed over large areas.	Plenty of good water at moderate depths, but held entirely in irregular joint cracks at variable distances apart.
Gneiss	do	Do.
Slate	Forms more than one-third of the area.	Generally plenty of good water. Occurs in irregular joint cracks, and to a moderate extent along highly inclined cleavage and stratification planes.
Schist	Irregularly distributed in slate and gneiss areas.	Do.
Limestone or marble..	Chiefly in Knox County, but existing also as thin bands in slate areas generally.	Abundance of hard water, chiefly in solution cavities.
Trap and volcanic rocks	Occur in several relatively small areas.	Small amounts of water, which are mostly rather high in mineral matter, but in some wells are as good as granite waters.
Unmetamorphosed sedimentary rocks.	Perry Basin, eastern Washington County, and other small areas.	Not tested, but probably contains plenty of water of good quality.
Gravel and sand	Widely distributed, especially in the valleys, 1 to 100 feet thick.	Large amounts of water. Of good quality where not polluted.
Till or boulder clay....	Covers the bed rock nearly everywhere; in many places underlies gravel and sand.	Water of variable amount and quality.
Clay	Locally distributed in the valleys and along the coast.	Contains little available water.

^aJackson, D. D., Water Supply Paper U. S. Geol. Survey No. 144, 1905, Pl. II.

DETAILED DESCRIPTIONS.

GRANITE AND GNEISS.

Description.—The granites and gneisses are very hard, dense, coarsely crystalline acidic rocks, and possess as a rule only microscopic pores. Granite being one of the hardest of rocks, drilling in it is difficult. Commonly a well in this rock is not deepened more than 3 to 5 feet a day, and sometimes not more than a few inches a day.

Distribution.—These rocks are widely distributed in Maine. Their boundaries are so irregular that their limits are best defined on a map rather than in a general description. The granite is represented by the brown color on Pl. I. There is some granite in nearly every part of southern and eastern Maine, but the largest areas are in Washington, Oxford, Cumberland, and York counties. As stated in the legend, areas covered by the granite symbol on the map include some small masses of a somewhat more basic rock, similar to granite, but of a darker color, known as diorite, and also moderate areas of gneiss, a somewhat banded type of granite, and of pegmatite, a rock of granitic composition but of very irregular and coarse texture.

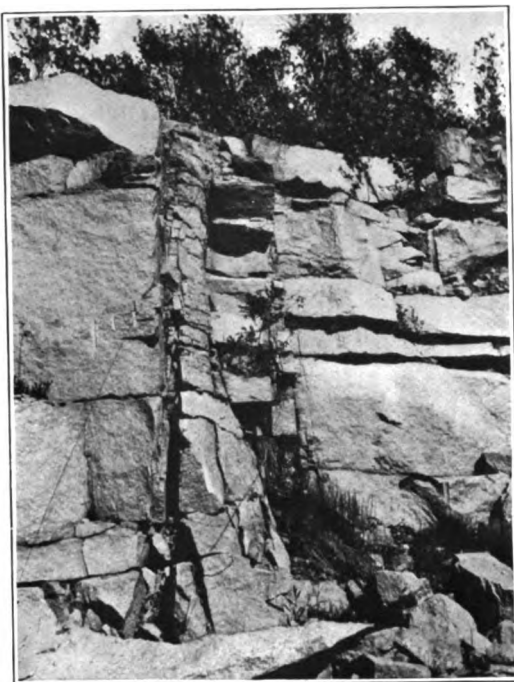
Relations to other rocks.—Where the granite occurs in large areas it extends downward to an unknown depth. In late Silurian or Devonian time the granites and gneisses, in a molten condition, were intruded into the sedimentary rocks which existed at that period. In many localities, as in York and Cumberland counties, the granite can be seen cutting across and inclosing masses of slate. An instance of this relation is seen in Pl. X, *B*, which shows a thin band of granite parallel with the stratification of the slate, the whole rock being much metamorphosed.

Joint cracks.—Practically all the water found in granite occurs in joint cracks. These joints generally form complex systems of intersecting planes (figs. 2 and 4). In southern Maine there are two principal systems. One of these—the horizontal joints, sheet joints, or “beds”—is approximately parallel with the surface of the ledge. Near the surface these joints are only a few inches apart, but they become many feet apart with increasing depth. In the J. C. Rogers well No. 1, near Stonington, 27 distinct “beds” of rock were penetrated in a depth of 94 feet. These ranged in thickness from a few inches to 14 feet. The thickest bed was passed through about midway from top to bottom in the well. The joints that are not sheet joints run in all directions, but in southern Maine the great majority of them, including the most persistent series, strike between N. 70° E. and S. 50° E. The hade of the joints, or the angle which they make with the vertical, varies, but except in the sheet joints it is generally small—from 0° to 30°. A zone of these vertical joints is illustrated in Pl. II, *A*.

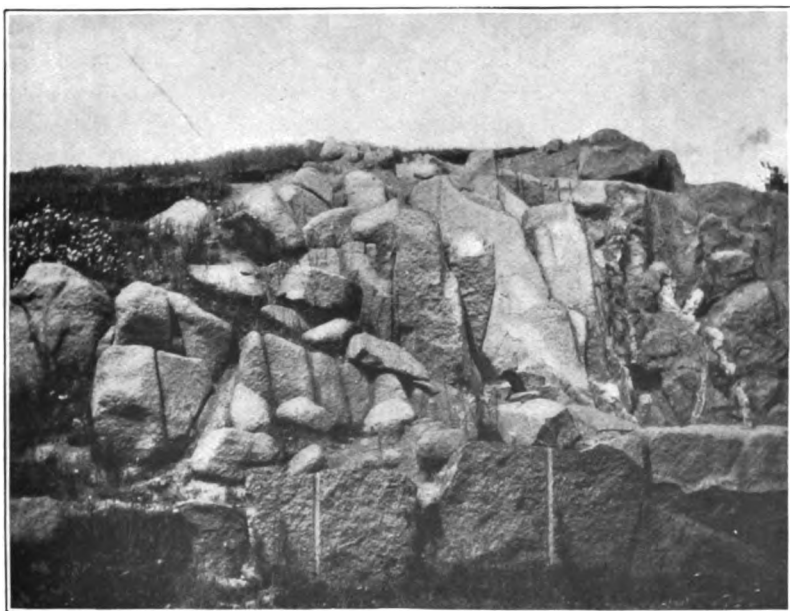
Structural relations of granite.—The structure of the granite in Hancock County, where it is extensively quarried, is typical of Maine granites, and its peculiarities will therefore be discussed in some detail. A number of quarries were visited with a view of obtaining information regarding the relations of rock structure to occurrence of water. In the quarries at Brooksville the principal system of joint cracks strikes S. 80° E. These joints are very numerous and persistent and are nearly vertical. They are, however, not open except near the surface. The second system, consisting of a few joints only, strikes S. 10° W. The sheet joints slope with the hill and the beds are in general from 1 to 5 feet in thickness. These conditions would seem to afford a good opportunity for water to penetrate downward parallel with the slope of the hill. In all the quarries there are some joints which do not seem to belong to either regular series, and some which are more open and would give a better opportunity for the downward penetration of water. One joint belonging to the principal series exposes an inch of decomposed granite that has been much iron-stained by percolating water. This crack was very wet, owing to water which is now penetrating along it. In some places granite along joint cracks is decomposed for a distance of 2 inches or more from the crack.

In another quarry in the same town the principal system of joints strikes approximately N. 20° W. and has a hade of 25° W. This system is continuous from the top to the bottom of the quarry, which is 20 feet or more in depth. The principal crack is one-fourth inch wide in places. When seen it was a little wet, but not iron stained or decomposed. In this system the joints are from 20 to 40 feet apart. A smaller system runs about east-west and has a hade nearly vertical. Other vertical joints do not belong to any of the regular systems. These irregular joints are much stained and tightly closed. They are generally from 2 to 10 feet apart and die out as they run against the more persistent joints of the principal series.

At Stonington a great deal of quarrying has been done and the conditions here are fairly typical of the granite on the Maine coast. The general strike and hade of the joints average the same as in other towns. Some cracks are, however, as much as an inch in width. One crack was found filled with a soft, greasy-looking mineral having a cleavage resembling that of calcite. As most of the quarries are on small islands, and some of them extend more than 100 feet below the sea, the sea water seeps in along the general system of joints and collects in the bottom of the quarries, whence it has to be pumped by windmill or engine. The sheet joints in the quarries at Stonington are nearly always dry. They slope toward the sea from the center of the hill, generally being 1 to 2 feet apart at the surface. Some of them are one-fourth to one-half inch in width and are filled with earth and rotten granite.



A. ZONE OF NEARLY VERTICAL JOINT CRACKS IN GRANITE QUARRY.



B. CONCENTRIC WEATHERING IN DIORITE AT PLEASANT RIVER GRANITE QUARRIES, DALOTVILLE.

Showing mode of entrance and storage of water along decomposition planes.

Water supplies.—Fig. 4 gives an example of the general arrangement of joint cracks. It will be seen that it is possible for water occurring in surface deposits to find its way downward to great depths, and that it will be tapped by any well which chances to strike a joint sufficiently open to form a part of the reservoir. The nearly vertical joints (Pl. II, *A*) and decomposition planes (Pl. II, *B*) generally serve as channels for the admission of water; the sheet joints serve as part of the reservoirs in which it is stored. As most of the joints are rather narrow, the amount of water yielded by them is likely to be only moderate, as a rule not more than 10 gallons a minute. Occasionally, however, as much as 30 gallons a minute has been obtained with a steam pump. The occurrence of water in granite is well illustrated by Pl. III, which shows water flowing from sheet joints in quarries at North Sullivan and Jonesboro. Similar flows have been observed at numerous quarries in Maine. In the R. A. Small well at Lisbon Falls a hand mirror was used to examine the bottom and sides of the well at frequent intervals during drilling, and water was seen to enter from all the sheet joints. In a few granite wells no water has been found.

On account of the extreme irregularity of joints in granite it will be seen that the success of any well in this rock is largely a matter of chance, dependent on whether the location is a fortunate one with reference to the arrangement of the joints. Fig. 4 shows how a well may (*a*) strike plenty of water within a few feet or (*b*) go to a great depth without success. Where the joints are numerous an increased amount of water may be found by deeper drilling, but in some places such continued drilling has found open cracks through which the water ran away.

As joints are most common near the surface and diminish in number as the depth increases, and as the pressure tends to make them close up with depth, the water supplies in granite are generally found within 100 or 200 feet of the surface. In an investigation of water in the crystalline rocks of Connecticut, Ellis^a concluded that as a rule it does not pay to drill below 200 feet. A prominent well driller of Maine who has drilled many wells in granite, in a calculation based on his experience, found that the average depth of the principal vein of water was 185 feet. While successful wells in which the principal vein is at a greater depth are often found, the probability of success by drilling below 250 feet seems to be less than it is by "pulling up" and starting a new well a few feet away. On account of the irregularity of the joints the new well is no less likely to be successful because a drilling near by has proved unsuccessful. One well drilled in gneiss at Auburn went to a depth of 654 feet without encountering any water. Few wells are complete failures, however.

^a Ellis, E. E., *Water-Supply Paper U. S. Geol. Survey No. 160, 1906, pp. 19-28.*

A few wells in granite yield natural flows of water. Usually, however, the water stands some distance below the surface.

Quality of water.—In quality granite water is as good as the best. The analyses on page 77 show that the total solids range in general from 40 to 200 parts per million, with occasional higher records. Analyses of granite waters from several wells along the coast have shown total solids running up to several thousand parts per million, but these proportions are mostly due to the inward penetration of sea water along open joints. In a few wells the amount of chlorine in granite harmonizes with the normal chlorine for the locality, but in most it is much higher. When this discrepancy can not be accounted for by pollution or by entrance of sea water it is believed that sodium or calcium chlorides exist in the rock. The calcium, magnesium, and sodium in granite are generally low, none of them being known to exceed 70 parts per million, and they are nearly everywhere below 30 parts. The carbonates may run as high as 150 parts, but are here and there as low as 10. Sulphates, if present, range up to 40, and silica from 5 to 30; potassium is not recorded above 10 parts. The general composition of granite water, as illustrated by analyses made in southern Maine, is represented by Pl. IV.

SLATE AND SCHIST.

Description.—The slate found in southern and eastern Maine is exceedingly diverse in character. Most commonly it is a fine-grained, moderately hard, dark-gray to greenish or black rock produced by the consolidation and metamorphosis of clay. In places it grades into true schist. In Aroostook County, southern Penobscot County, and a few other localities the slate is locally slightly calcareous. Practically all the slate in this State is highly folded, and the stratification and cleavage planes stand on edge. Near the coast the strike is variable, but in Kennebec and Penobscot counties it is very constant, being about N. 60° E. over broad areas. The dip is not so uniform, but is nearly everywhere high. As these rocks range from very hard to very soft, the speed of well drilling varies proportionately. Generally 2 to 10 feet a day can be accomplished, but one well is reported to have been sunk 35 feet in a single night.

Distribution.—Nearly half the area covered by this report is underlain by slate and schists. The areas are so irregular that they can not be well described, but they are shown on Pl. I by the green color. Slate is much more abundant in the northern part of the area than in the southern part, and north of the forty-fifth parallel it is still more predominant.

Relation to other rocks.—At many points in York and Cumberland counties and elsewhere the slate and schist can be seen to be cut by granite, proving that the sedimentary rocks in that part of the State



A. SECTION OF GRANITE QUARRY AT JONESBORO.

Showing water issuing from sheet joints.



B. VIEW IN CRABTREE & HAVEY'S GRANITE QUARRY, AT NORTH SULLIVAN.

Showing occurrence of water in sheet joints.

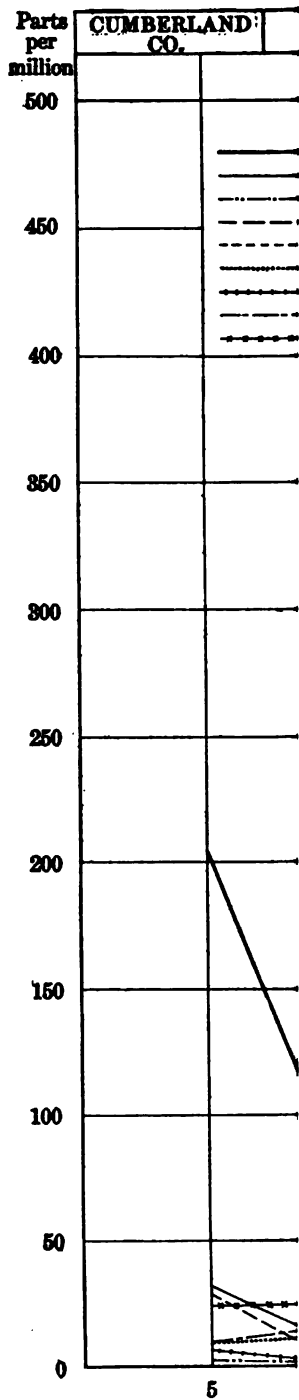


DIAGRAM ILLUSTRAT'

are older than the principal granite masses. In the Penobscot Bay quadrangle the slate and schist (Penobscot formation) have been shown to be probably of Cambrian age, and most of the similar rocks of southwestern Maine are believed to be of the same age. The Ellsworth schist is slightly older, but may also be Cambrian. All the regionally metamorphosed rocks are Ordovician or older, as the movements which produced metamorphism took place about the close of Ordovician time. The high folding and extensive metamorphism of these rocks over wide areas make them all of the same class so far as the underground-water conditions are concerned.

Stratification, cleavage, and fissility.—The slates over most of Maine show clear evidences of stratification, but have been subjected to so great pressure that the dip is everywhere at a high angle, generally within 30° of the vertical. The strike along the coast is somewhat variable, but throughout most of Kennebec and Penobscot counties it is rather constant, in few places departing much from N. 60° E. Most of the slate and schist is rather easily cleavable, and as a rule the cleavage and foliation planes correspond in strike with the stratification, but vary somewhat in dip. The cleavage, foliation, and stratification planes are generally tightly closed at considerable depths, but rather open near the surface, and in many regions they allow passage for small quantities of water.

Joint cracks.—What has been said regarding joints under the description of granite will also apply in a general way to slate and schist, except that in these rocks the cracks are more irregular in direction, extent, and characteristics. On account of the difference in structure of slate, its joints are not conspicuous, but they can be depended on for water supplies. Where they are flat, they have little effect on drilling, but in numerous places the slate is much cut up by joints, many of which are inclined. These often work havoc with drilling tools. If an inclined joint plane is hard and smooth, the drill may glance off and give a crooked hole. If the joint plane is soft, the drill may get stuck, and sometimes many days are required to remove it, or the hole may have to be abandoned altogether.

Water supplies.—Slate is generally supposed not to contain much water, but in Maine it has proved to be the most productive rock. As in granite areas, the water is first stored largely in superficial deposits of gravel and boulder clay. In the slates and schists, however, the water penetrates downward not only through joint systems but also along small fissures which follow the stratification and cleavage planes. An illustration of the way water may find its way below the surface from overlying drift is given in Pl. V, A, and Pl. VII, A, the first view showing the effect of stratification planes and the second of joint cracks.

On account of the more numerous means of admission of water larger quantities are generally expected and found in slate than in granite. Few wells drilled in slate in southern Maine have met with absolute failure. Instances in which only a gallon or two of water a minute has been found are due generally to the insufficient depth of the well.

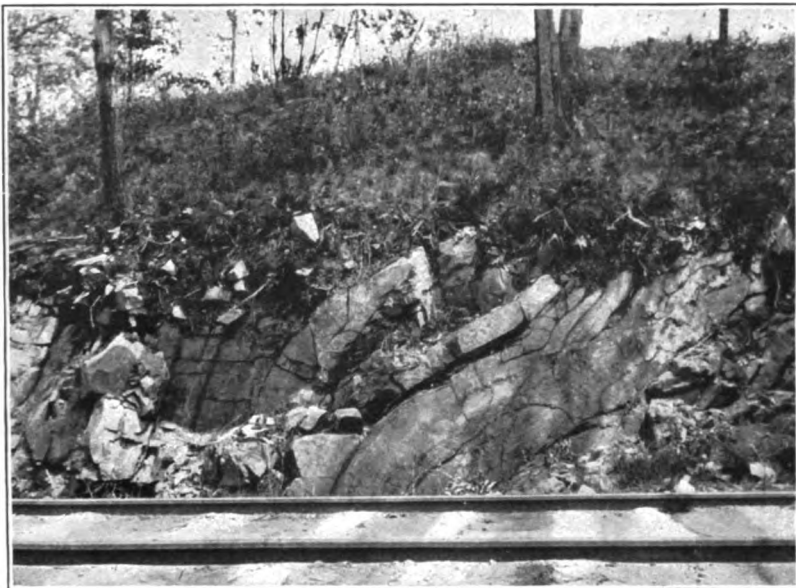
The depth to which it is advisable to drill in slate differs somewhat in various parts of the State. In some places along the coast and near the areas of intruded igneous rocks, where the slate has evidently been under great pressure, the statement made with regard to granite, that it is not desirable to drill deeper than 250 feet, seems to hold true. In the large slate areas of the interior, however, wells drilled much deeper than that seem to afford supplies which increase with depth. Some of the best wells in the State are more than 300 feet deep, and so far as known there have been no failures among these deep holes. Hence in the large slate areas it is well to drill as deep as 400 or 500 feet unless sufficient supplies are obtained nearer the surface. In general, the water in slate is not all obtained in any one vein, but small supplies are found in a number of veins, and it is by the repeated tapping of new veins that a sufficient supply is finally obtained. The amount of water supplied by most slate wells less than 100 feet in depth is between 1 and 10 gallons a minute. In many of the wells of greater depth, however, the supplies run up to 30 gallons a minute, and in a few localities, as at Searsport, wells pumped by steam pump have been reported to yield more than 50 gallons a minute.

A prominent well driller of Aroostook County calculates that in that part of Maine the average depth of wells is 81 feet. In Bangor and vicinity drilling frequently has not been successful at first, but rather than go deeper the driller has moved the machine 5 to 10 feet and a good supply of water has been obtained. Such cases resemble the occurrence of water in granite.

That large open cracks exist in slate is proved at Sorrento, where two salt-water wells were obtained on a peninsula, indicating the penetration of sea water inward from the ocean. In Islesboro cracks and cavities are numerous. These are most common 30 to 40 feet from the surface, and few occur below 100 feet. They are supposed to be due to the solution of beds of limestone, and the permanent supplies from this source are only 2 to 3 gallons a minute.

The best and largest supplies in southern Maine are obtained in slate and schist below 100 feet.

The head of water in slate is very uncertain, depending on the topographic situation of the well and the arrangement of the systems of water passages in the rock. The water level may stand anywhere between the bottom and top of the well, but is commonly a few feet below the surface.



A. OUTCROP OF SLATE IN RAILROAD CUT AT KITTERY JUNCTION.
Showing fracture of rock along bedding and possibility of water entering from overlying drift.



B. COMPLETED WELL BELONGING TO CRABTREE & HAVEY, AT NORTH SULLIVAN.
Showing proper mode of protection of well drilled in granite.

Strange as it may seem to those who know the structure of slate, a few flowing wells have been struck in this rock. Such wells do not appear to have any regular distribution, and there are in general not more than one or two in a town. Two of them are in Westbrook, two in York, two in Islesboro, one at Bangor, and several elsewhere in the region. The flow seldom exceeds 3 gallons a minute. It is generally caused by the pressure of water following downward along systems of joint cracks from neighboring hills (see fig. 4), and the water rarely, if ever, in this region comes from a distance. The best flowing wells in Maine are at Greenville, Piscataquis County, where there are several from which the water will rise 10 to 14 feet above the surface. These will be described in the report on the underground waters of northern Maine.^a

Quality of water.—In quality the slate water of southern Maine may be said to be the best for drinking purposes, and except in Waldo and Penobscot counties it is seldom hard. According to the analyses which have been made (see pp. 78–80), the total solids run from 25 to more than 800 parts per million. In order to show graphically the general character of slate water Pl. VI has been prepared. A separate line is given for each constituent of the water, and it will be seen that there is some similarity in the composition of the water from different localities.

Occasionally the water found in slate contains small quantities of iron, but these are rarely sufficient to be objectionable. In Waldo and Penobscot counties the amount of calcium and magnesium carbonates is high and produces some scale in boilers. Waters in these counties are generally called “hard,” but are only of moderate hardness when compared with many waters in the Central States that are used for a great variety of purposes.

LIMESTONE.

Character and distribution.—In southern Maine the limestones are restricted to a type of dense crystalline limestone which is found practically only in Knox County, in the towns of Rockland, Rockport, Camden, Thomaston, and Warren. The rocks consist of a number of bands of limestone associated with slate, schist, and quartzite. (See Pl. I.) These bands are not more than a mile in greatest width and extend in a general northeast-southwest direction. In Islesboro there are local beds of similar limestone, all very thin and interstratified between vertical slates. These thin limestones of Islesboro are unimportant, except as they furnish a large proportion of calcium carbonate in the water and interfere with well drilling. The distribution of the limestones of Knox and Waldo counties is

^a The report for the northern part of the State is in preparation.

shown in detail in the Rockland folio.^a These limestones are believed to be all a part of the same geologic series, and were formed at the same period as most of the slates of central Maine and of Waldo and Knox counties.

Solution cavities and channels.—The waters in limestone occur mainly in open channels, caverns, etc., dissolved in the rock by the water itself. The water probably originally followed joint or bedding planes, which were gradually enlarged by solution and formed the cavities that we now find. One of these channels, exposed in the side of an abandoned quarry, is illustrated in Pl. VII, B. The occurrence of these channels within the limestone is very irregular and their location can seldom be predicted. Most deep wells drilled in the limestone, however, will probably encounter one or more such passages.

Water supplies.—The waters in limestone are hard but are not commonly mineralized in other respects. There is a considerable likelihood of pollution, owing to the fact that much of the underground water occurring in limestone has found its way downward through definite channels and has carried with it more or less surface wash. A single analysis of limestone water is given in the table on page 86 (No. 255). This water was collected from a spring in the bottom of a deep quarry near Rockland. No other analyses were made, as no wells have been drilled in limestone (except wells on Islesboro, which are largely in slate but pass through thin layers of limestone). The large amount of water pumped daily from these quarries and the common occurrence of springs in them indicate the probable existence of considerable quantities of water in these rocks.

At Islesboro the drillers report numerous cracks below 50 feet in depth, and occasionally pockets 3 to 4 feet in size are found. These generally supply abundant water for a few minutes or hours, but the supply soon gives out, so drilling is never stopped at a pocket. Although these wells are in a slate region, the pockets are supposed to occur in thin beds of limestone which have been partly dissolved.

VOLCANIC AND OTHER IGNEOUS ROCKS.

Character and distribution.—In the extreme western part of Hancock County, on many of the islands in Penobscot Bay, on the southern edge of Mount Desert Island, and in eastern Washington County, there is a class of rocks represented on the map (Pl. I) by the red color. These rocks are principally volcanic in origin and consist of flows of andesite, rhyolite, diabase, etc., and of beds of tuff or volcanic ash. On a map of this scale it is not possible to represent all the various types of these rocks, even if the limits of all the areas were definitely known. In Hancock and Knox counties the mapping

^a Geologic Atlas U. S., folio 158, U. S. Geol. Survey, 1908.

Parts
per
million

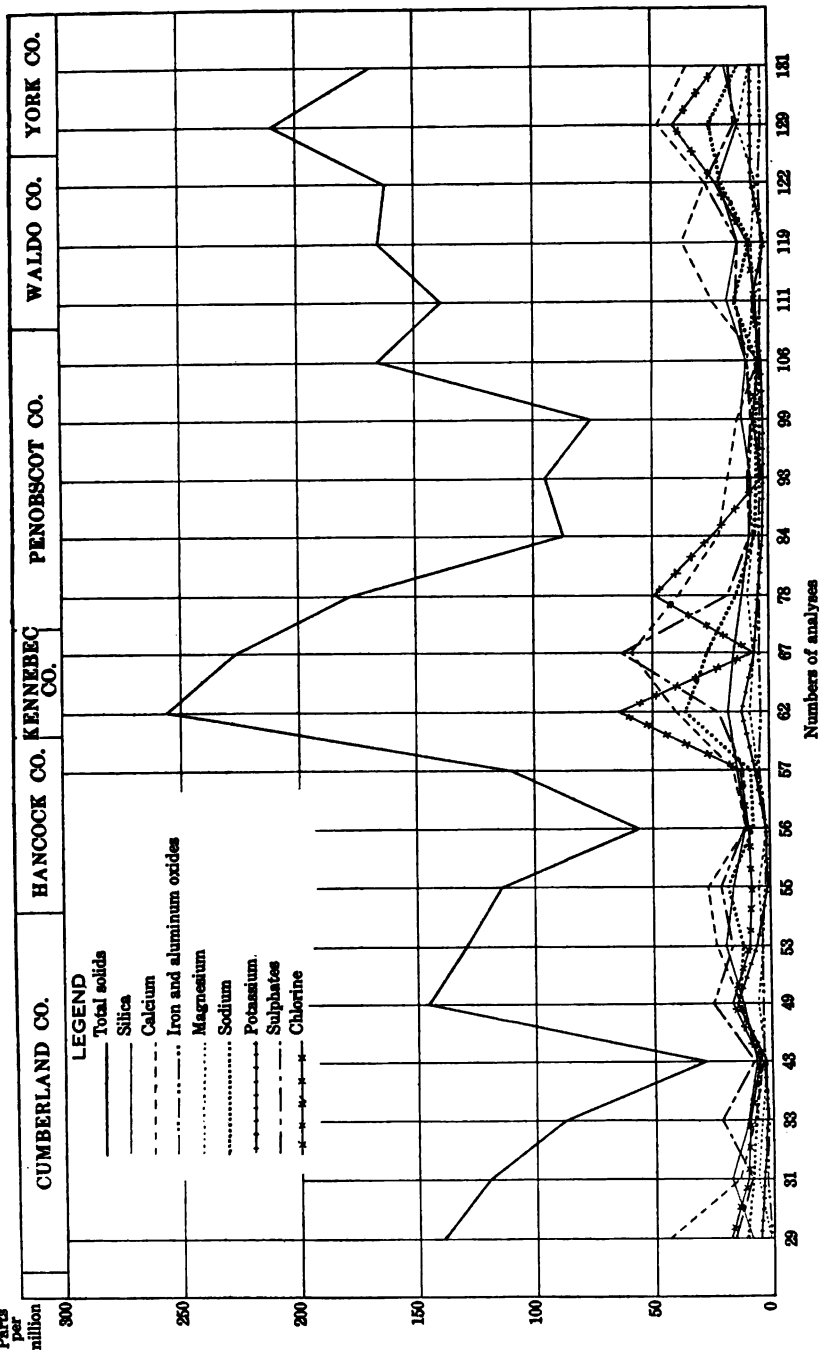
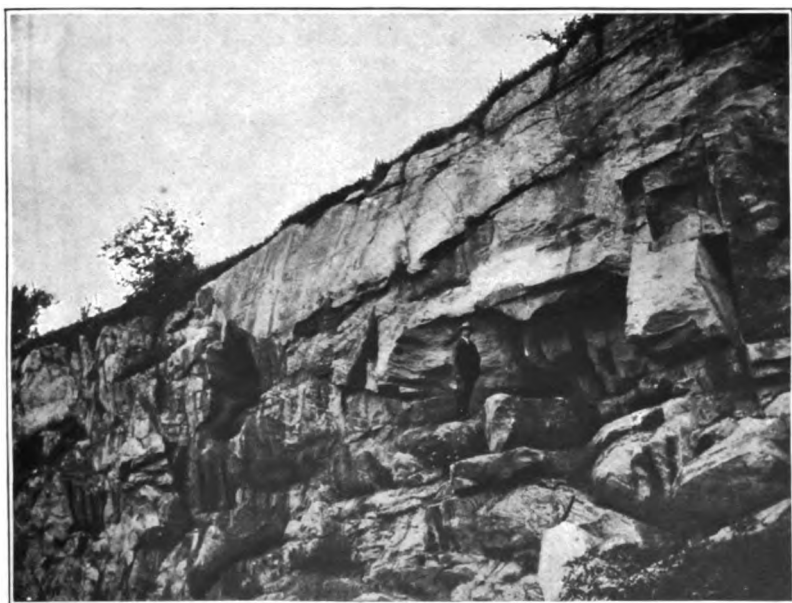


DIAGRAM ILLUSTRATING CHEMICAL COMPOSITION OF WATER FROM SLATE IN SOUTHERN MAINE.



A. OUTCROP OF SLATE BELOW TILL IN RAILROAD CUT AT KITTERY JUNCTION.

Showing vertical joint cracks and overlying cover of till in which water is held.



B. SMALL CAVE AND SOLUTION CHANNELS IN LIMESTONE.

Showing old water passages, Rockland.

is based on the detailed maps of the Penobscot Bay folio.^a In Washington County the limits of the volcanic rocks are not so accurately known.

Besides the areas of volcanic rocks represented on the map, there are small dikes of trap rarely more than a few feet in width. These are intrusive in the slate and granite throughout the coast region, and are geologically among the most recent rocks in the State.

Water supplies.—On account of the manifold nature of the volcanic rocks, no comprehensive statements can be made concerning the water supplies they contain. Wells in these rocks are, however, much less sure of success than those in granite. In Castine several wells drilled in acidic volcanic tuff obtained moderate supplies, but one was an entire failure. In a 625-foot well at this place no water was found below 425 feet. At North Haven several wells drilled in basic lava flows get fair amounts of water, but some wells here were but partially successful. On Suttons Island, off Mount Desert, a well in trap is reported to yield 26 gallons a minute when pumped with a gasoline engine, but wells on neighboring islands were either unsuccessful or obtained only from 1 to 5 gallons a minute. At Eastport and Lubec several wells sunk in greenstone seem to give moderate amounts. One well at Eastport was a flowing well.

Quality of water.—On account of the small areas covered by these rocks in Maine only half a dozen analyses have been made. These are given in the table on page 81 and are represented graphically in Pl. VIII. It will be seen that the one greenstone water analyzed showed 413 parts per million of total solids, of which 108 were calcium, 42 were organic and volatile matter, and 71 were sulphates. A field assay of the same water showed 214 parts of bicarbonates, this being about as hard as the average of the slate waters in Penobscot County. The first analysis of trap water (No. 155) is so high in mineral matter that it is supposed to be partly sea water, and should not be considered as typical of trap waters in general. The second analysis of trap water is more moderate, showing only 90 parts of total solids. The proportions of the various elements in this water are very low for a well water. When trap waters are used they seem to be fairly good for both drinking and washing.

UNMETAMORPHOSED SEDIMENTARY ROCKS.

A few small areas in eastern Maine are occupied by unmetamorphosed sedimentary rocks, but only one of these—Perry Basin, in eastern Washington County—is of sufficient size to be mapped. (Pl. I.) This area is described by Smith.^b The rocks were found to be conglomerates, sandstones, and some interbedded rhyolitic

^a Geologic Atlas U. S., folio 149, U. S. Geol. Survey, 1908.

^b Smith, G. O., Prof. Paper U. S. Geol. Survey No. 35, 1905.

lavas. They are of Devonian age, and were named the Perry formation. No drilled wells are known to have been sunk in these rocks, and hence little is known of the underground water conditions. To judge from similar rocks in other localities, they ought to hold plenty of water of good quality. In the same region are considerable areas of Silurian shales.

AREAS OF COMPLEX.

Character and distribution.—On Pl. I large areas in Oxford, Androscoggin, Sagadahoc, Lincoln, Knox, and Waldo counties and portions of adjacent counties are represented by a buff color. These areas are occupied by what is known as a complex, consisting of slates and schists intimately intruded by granites, gneisses, and basic volcanic rocks. The rocks in eastern areas, or those lying east of Brunswick and Augusta, are more slaty, and those in the western areas are more granitic, but they can not be differentiated on the map.

Water supplies.—As a rule water from areas of complex that are of notable size is more uncertain in quantity and quality than that from either granite or slate. Some good wells have been obtained in these areas. In many wells in Lincoln county the water has a peculiar taste, which sometimes makes it unfit for use. The water is known to have a bad effect on the well casing, frequently eating holes through it in a surprisingly short time, and the solution of the galvanized iron may possibly be a factor in the taste of the water. In some wells the taste may be due to iron, but as iron is absent in the greater number of these waters, this is not the chief cause. A review of the analyses of waters from the complex (p. 81) shows that they average higher in sulphates than those from either granite or slate. This indicates that they may contain free sulphuric acid. The sulphates range from a trace up to 77 parts per million. One field assay reports 286 parts per million. The total solids run from 95 to 301 parts per million in samples which were tested for them. As a rule the waters in the more granitic portion of the complex area are rather poor in quality, containing considerable iron and other minerals, whereas that from the more slaty portion is better.

SURFACE DEPOSITS OF SOUTHERN MAINE.

PRINCIPAL TYPES.

The surface deposits in Maine consist of stratified and unstratified clay, sand, and gravel and of till or bowlder clay. With the exception of some modern beaches, these surface deposits, which are known collectively as "drift," were laid down directly or indirectly through the agency of vast continental glaciers that covered New England at several periods during the last million years. Materials

U. S. GEOLOGICAL SURVEY

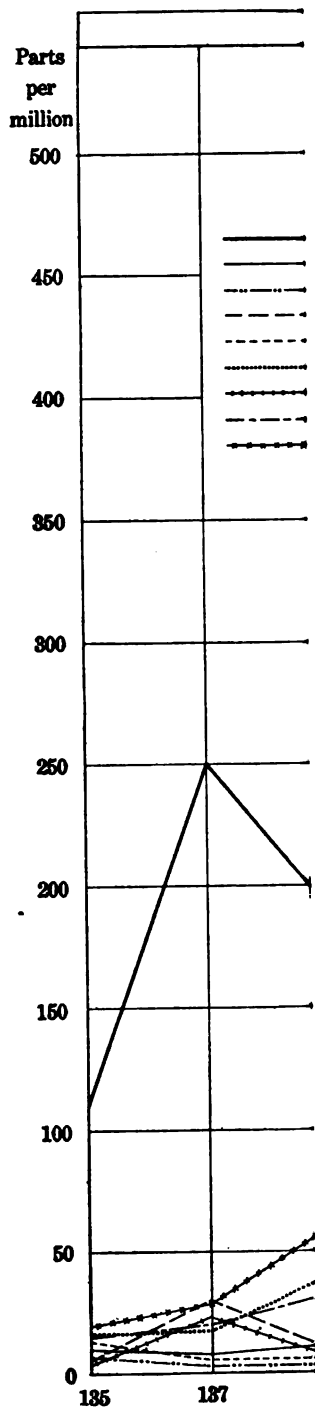


DIAGRAM ILLUSTRATION

formed by the grinding action of the ice in passing over the rocks and former surface deposits were, when the ice retreated, left as the heterogeneous deposits of till or boulder clay which now cover large areas in both the uplands and the valleys. During the occupation of the region by ice, glacial rivers laden with sand and gravel flowed upon or under the ice, and the deposits made in their channels now appear as long, winding gravel ridges, known as "eskers." During the times when the ice was stationary great quantities of sand and gravel were often discharged into the sea, into glacial lakes, or onto the land surface to form deltas and sand plains. Irregular water-laid deposits, formed in connection with the ice, are known as "kames." When the ice finally melted it did not retreat steadily, but often halted, perhaps for years at a time, and during such halts a ridge or a succession of hills of sand, gravel, till, and boulders was sometimes formed at the ice front, of material pushed up by the glacier or deposited by glacial waters. Such deposits are known as "moraines."

The writer has found evidence that since the first glaciation there have been interglacial periods.^a During such an interglacial stage the land seems to have stood at a lower level than at present, and there was deposited in the sea a widespread bed of stratified clay, which now extends for great distances along the coast and more than 100 miles up the larger valleys. This has been known as the *Leda* clay, from a species of fossil shell which it contains.

In order that the occurrence of water in the surface formations may be well understood, they will be described in some detail, in the order in which they originated.

DETAILED DESCRIPTIONS.

BOWLDER CLAY, OR TILL.

Character and distribution.—Boulder clay, or till, is the principal drift deposit of Maine. It consists mainly of a heterogeneous deposit of clay, sand, gravel, and boulders, showing as a rule no trace of stratification and containing boulders up to several feet in diameter. Its thickness ranges from a few inches to more than 100 feet. Usually it is very hard and tough, and is called "hardpan," though this term is also applied by well drillers to other formations.

This material is probably the most widespread deposit in Maine, overlying the bed rock nearly everywhere, and generally underlying the surface sand, gravel, and clay deposits, where the latter are present. In places in southwestern Maine till occurs segregated in the form of lenticular hills, known as "drumlins." These are often from one-fourth mile to a mile in greatest length and 100 to 200 feet in height, and are composed entirely of the hardpan type of boulder clay.

^a Complexity of the glacial period in northeastern New England: Bull. Geol. Soc. America, vol. 18, 1908, pp. 505-556.

Water supplies.—Where typical and occurring in thick deposits, as in drumlins, boulder clay can not be said to yield a large amount of water. Wells dug in drumlins are generally dependent on surface water and frequently run dry in summer. The scantiness of the supply in drumlins is due to the large proportion of clay in this type of till, rendering it impervious. Where the till fills depressions and covers gentle slopes, however, it is in many places of more variable character, locally containing gravelly and sandy layers, and here and there having openings which form rather definite water channels. For this reason the degree of success with wells in till varies greatly, but in the aggregate the till yields a large amount of water. Generally wells of large diameter are most successful, as they offer a better opportunity for intercepting a "vein." Water obtained from till is generally of good quality for all uses, unless situated within the range of contamination from surface drainage. If the water once becomes polluted it may retain its dangerous character for a long time and for a considerable distance.

Water occurring in till is generally found within a few feet of the surface. As a rule it is not under pressure, however, and will not rise above the point at which it is encountered. The volume at any one time is not generally large, but there is a constant slow inflow. Water is abundant in a wet season or after a rain, but a large proportion of wells in till run dry in summer.

SAND AND GRAVEL.

Character and distribution.—Sand and gravel deposits are known collectively as "modified drift," for the reason that they are composed of till which has been reworked and assorted by water. Such deposits occurring in the form of flat or gently sloping plains are known as sand plains, deltas, or outwash deposits; those formed in long ridges on or under the ice are known as eskers; and those deposited as irregular hills near the ice front are known as kames or moraines. Many of these deposits are of great thickness. They all consist of pebbles and grains of sand, derived from a great variety of rocks.

Sands and gravels are widely distributed throughout the State. Moraine, kame, and esker deposits may occur in nearly all situations, though most commonly in the lowlands. Sand plains and outwash deposits are situated mostly along the valleys and lakes and within a few miles of the coast. Some of these plains are very extensive, covering many square miles of surface.

Relation to other deposits.—Most of these deposits overlie the principal body of till, although local beds of gravel are found underneath the till and in a few places gravelly layers occur in the till itself.

Gravel is also variable in its relations to clay deposits. Along the coast and in the valleys of Androscoggin, Kennebec, Penobscot, and other large rivers many extensive deposits of coarse gravels underlie

the clays, and in such places the upper surface of the gravel is likely to be undulating. In other places sand and gravel overlie the clay.

Water supplies.—Sands and gravels are very porous; in many of them 30 per cent of the volume is made up of free space between the grains. In such materials the whole mass is saturated below the water level, and when penetrated by wells copious supplies are quickly yielded. The waters are generally of good quality, and in Maine they contain less mineral matter than waters from most other types of deposits.

In passing downward through the sands surface waters are subjected to natural filtration and the substances with which they may have originally been polluted are frequently changed to harmless chemical compounds. In gravel and in the coarser types of sand the water moves more rapidly and the conditions are less favorable for filtration, so the waters may remain polluted. In general, however, waters from sands and gravels, if taken from a considerable distance below the surface, are safe to use. Plenty of water may generally be found at 10 to 20 feet, but supplies from greater depth are much safer.

In the sands and finer gravels the cheapest and best method of obtaining water is by driven wells, which can be sunk quickly and at very slight cost. In the very fine sands or quicksands, however, it is very difficult to exclude the material from the pipes, the quicksand frequently penetrating the well and clogging the pipe or ruining the pump. Because of the readiness with which sands and gravels yield their water, wells located close together frequently affect one another, some wells drawing water away from others. The ease of movement of the water is also the cause of great fluctuations in the level of the surface of the saturated zone, which falls rapidly after wet seasons. To procure permanent supplies the wells should penetrate to the level which the water surface occupies in the driest seasons.

CLAY.

Character and distribution.—The clay deposits of Maine differ greatly in composition and in origin. The most common type, however—a widespread formation of rather uniform character—is a light-gray or brownish, fine-grained, thin-bedded deposit, ranging from plastic to tough, but so dense as to be almost impervious to water. It is of marine origin, as shown by fossil shells which it contains in many places. In some localities there are thin layers of sand stratified with the clay. The thickness of this principal clay bed is generally not more than 20 to 30 feet, but in some of the deeper valleys and along the coast it may be as much as 100 feet.

Clay is widely scattered, but in general it occurs near the coast or in the valleys within 100 miles of it. Near the sea it occurs as

flat or gently sloping plains rising from 15 to 80 feet above tide. That these plains have been deposited in comparatively recent time is shown by their flat surface and the slight erosion they exhibit. Farther back from the coast, and in the valleys of Piscataqua, Saco, Presumpscot, Androscoggin, Kennebec, Penobscot, and other rivers, there are clays at higher levels, in some places above 200 feet, and in a few reaching 300 feet. The highest elevations are found in the Kennebec Valley, but in general the upper limit is little more than 200 feet. These high-level clays are best preserved in situations more or less protected from erosion, and when they occur in the main valleys they are much eroded, suggesting that they may be older than the coastal clays.

Relation to other deposits.—Where clay occurs it nearly always overlies the principal till deposit. In many localities, however, 3 to 5 feet or more of gravelly till rests on the clay. Gravel may overlie or underlie clay, or both. The clay is generally, but not invariably, unconformable with both the underlying and the overlying deposits.

Water supplies.—Clay is so impervious that in itself it contains little or no water which can be utilized as a source of supply. Water is frequently reported in clays, but it usually occurs in more or less sandy layers. In some places sand which approaches clay in fineness and which is sometimes mistaken for clay yields considerable water.

Clay is of greatest importance, not as a water bearer, but as a confining layer to porous sands, the water in which it prevents from escaping. In large areas it is overlain by sand which contains much water, resting on the impervious clay and moving slowly riverward or seaward.

The waters of clays, because of the fineness of the material, come into contact with relatively large amounts of mineral matter and frequently become mineralized, lime and salt being the most common substances dissolved. These waters are, as a rule, free from contamination. When, because of the absence of other sources, it is necessary to obtain supplies from clay, a well should be sunk with as large a diameter as practicable and be continued beneath the point at which the water is obtained to a sufficient depth to furnish ample storage capacity, as clay waters are slight in amount and are yielded very slowly. Dug wells are usually most satisfactory where the clay is near the surface, but such wells should be carefully covered and guarded from all sources of pollution.

OUTLINE OF GEOLOGIC HISTORY.

In order to make clear the relations of the various water-bearing and impervious formations of Maine a brief summary of the history of these formations is given. As a complete geologic investigation of

the State has never been made, little can be said regarding the rocks, but the sequence in which they were formed will be briefly reviewed.

The oldest formation in the southern part of the State is probably the Ellsworth schist,^a of Cambrian age. Muddy sediments that subsequently became slates were deposited over large areas originally, but at the close of Ordovician time there was a long period of dynamic metamorphism in which these slates were turned on edge, cracked and broken, and intruded by molten granite, which now fills cracks in the slate and constitutes the surface over wide areas. The volcanic action may have extended into Devonian time. In some later age the trap dikes which penetrate the slate were formed by intrusion of a basic type of molten lava. Some slates, sandstones, and other rocks may have been formed after the intrusion of the dikes.

After the formation of all the solid rocks of Maine and their metamorphism and folding there were long ages during which few deposits were made in this part of the country, and the land was eroded into hills and valleys and brought into substantially its present relief. Then came the series of great glacial invasions which covered the State with a thick coating of drift. After the deposition of till and gravels and the retreat of the ice of the first invasion there was a long interglacial stage during which erosion removed the greater part of the glacial deposits, so that they are now found only in patches beneath the more recent till sheets.

The next glacial invasion of which we have any record is the one during which the greater part of the Maine boulder clay was formed. During the subsequent disappearance of the ice coarse gravels were deposited in the valleys and along the coast, after which the widespread formation of marine clay took place. Later the land was elevated and the clay was deeply eroded. Still later the ice advanced again, depositing a few feet of a more gravelly type of till over some of the clay deposits. During the retreat of this final ice sheet immense deposits of sand and gravel were formed in most of the valleys and fresh marine clays were laid down along the coast. By subsequent uplift these clays have now reached an elevation of 20 to 80 feet above the sea, and form extensive plains in some localities.

RECOVERY OF UNDERGROUND WATER.

GENERAL STATEMENT.

Underground water can be obtained naturally, as it emerges from the ground in the form of springs, or artificially, by means of wells or collecting galleries. These methods and their bearing on the underground-water problems of Maine will be discussed separately.

^aThe Ellsworth schist is described by G. O. Smith and E. S. Bastin in the Penobscot Bay folio (No. 140) of the Geologic Atlas of the United States, published by the United States Geological Survey.

SPRINGS.

Classification and emergence.—Wherever the water table or a water-bearing bed intercepts the surface of the ground a spring is formed. Springs are of various types. The waters may percolate through pores in the surface deposit or through passages in sand and clay, and these are known as seepage springs. They may traverse limestone or other soluble strata, dissolving passages for themselves, and finally emerge on a hillside, or they may flow out of fissures along joint cracks or fault or contact planes and be known as fissure springs. The term "fissure springs" is used rather comprehensively to include the springs issuing along bedding, joint, cleavage, or fault planes. The distinguishing feature is a break in the rocks along which the waters can pass, it being immaterial whether any considerable open space exists. Springs may occur in almost any topographic situation, even on a plain, but they are most common on steep hillsides.

The common method of classifying springs is by their predominating mineral constituents. Since the days of Aristotle many different classifications have been invented, and at the present time several are in use. The classification most commonly accepted in the United States is that of Peale,^a who divides all mineral springs into two great groups—nonthermal or cold, and thermal—and into five classes with reference to chemical ingredients, viz, alkaline, alkaline-saline, saline, acid, and neutral or indifferent. Some writers use the term "chalybeate" for the fourth class instead of acid. This classification is easily subdivided, according to the predominant solid constituents of the water, which may be sodic, lithic, potassic, magnesian, salicic, iodic, bromic, arsenical, siliceous, manganic, aluminous, etc. The terms "nongaseous," "carbonated," and "sulphureted" designate the existence or nonexistence of gaseous contents.

The majority of mineral springs in Maine are either neutral or light alkaline-calcic or alkaline-chalybeate; only a few springs would fall in the other classes. They are not classified in this report, as the analyses (pp. 84-87) give a much better idea of their character.

Number and importance in Maine.—Springs are abundant in Maine, especially in the interior of the State. Very many are situated on hillsides, from which the water can be distributed by gravity to residences and farms. In places several families have combined and have distributed the water of the larger springs through their dwellings by pipes. Here and there the water is raised by windmills.

The water is very cool, temperatures as low as 45° being common and temperatures over 50° seldom reported. The spring waters are therefore valuable for dairy and creamery purposes.

^a Peale, A. C., *Natural mineral waters of the United States: Fourteenth Ann. Rept. U. S. Geol. Survey*, pt. 2, 1894, p. 66.

Springs are more generally utilized in those parts of the State where the well water is hard than where it is soft. In a few places, where the quality of water in the neighboring streams is poor, springs supply manufacturing establishments.

Information previously published.—The earliest publication regarding the mineral springs of Maine was made by Goodale in 1861.^a The data contained in this report, consisting of a few analyses, temperatures, etc., were recompiled by Peale^b in 1886. A few springs were described in 1899 by Crook.^c Otherwise no information has been published regarding Maine springs except the reports of sales given in the Geological Survey's annual reports on the mineral resources of the United States.

Commercial springs.—A group of springs of great economic value to the State comprises those which are designated commercial springs, or those of which the waters are sold by measure. In this group there are two subclasses. The first includes springs that furnish table water to consumers in their vicinity at regular intervals. The second subclass comprises springs the waters of which are bottled and shipped to distant points, including the mineral springs whose waters are commonly supposed to possess medicinal properties, and also certain other springs the water of which is exceptionally pure. The sales of water from these two classes amount annually to more than \$100,000, not including the sales of water from Poland Spring, the proprietors of which decline to make any statement as to the quantity or the value of the water supplied by them. It is believed, however, that the aggregate value of the water shipped from this spring is greater than that of the water from all the other springs in the State.

Altogether the springs reporting sales in southern Maine at the time this investigation was made (1906) were 44 in number, as follows:

Addison Mineral Spring, Addison, Washington County.
 Arctic Spring, Bangor, Penobscot County.
 Baker Puritan Spring, Old Orchard, York County.
 Bluehill Mineral Spring, Bluehill, Hancock County.
 Carrabasset Mineral Spring, Carrabasset, Franklin County.
 Chapman's Spring, Brewer, Penobscot County.
 Cold Bowling Spring, Steep Falls, Limington, York County.
 Crystal Mineral Spring, Auburn, Androscoggin County.
 Forest Spring, Litchfield, Kennebec County.
 Glenrock Mineral Spring, Greene, Androscoggin County.
 Glenwood Spring, St. Albans, Somerset County.
 Highland Spring, Holden, Penobscot County.
 Highland Mineral Spring, Lewiston, Androscoggin County.
 Hillside Spring, Bangor, Penobscot County.
 Indian Hermit Mineral Spring, Wells, York County.

^a Goodale, G. L., Report on the mineral waters of Maine: Sixth Ann. Rept. Maine Board of Agr., 1861.

^b Peale, A. C., Mineral waters of the United States: Bull. U. S. Geol. Survey No. 32, 1886, pp. 13-16.

^c Crook, J. K., Mineral waters of the United States and Canada.

Ishka Springs, West Hancock, Hancock County.
 Katagudos Spring, Eastbrook, Hancock County.
 Keystone Mineral Spring, East Poland, Androscoggin County.
 Knowlton's Soda Spring, South Strong, Franklin County.
 Mount Desert Spring, Bar Harbor, Hancock County.
 Mount Hartford Mineral Spring, Hartford, Oxford County.
 Mount Oxford Spring, Sumner, Oxford County.
 Mount Zircon Spring, Milton Plantation, Oxford County.
 Oak Grove Spring, Brewer, Penobscot County.
 Olde Yorke Spring, Old Orchard, York County.
 Oxford Spring Home, Oxford, Oxford County.
 Paradise Spring, Brunswick, Cumberland County.
 Pejepscot Spring, Auburn, Androscoggin County.
 Pine Spring, Topsham, Sagadahoc County.
 Pine Grove Spring, Pittsfield, Somerset County.
 Poland Spring, Poland, Androscoggin County.
 Pownal Spring, New Gloucester, Cumberland County.
 Pure Water Spring, Waterville, Kennebec County.
 Raymond Spring, North Raymond, Cumberland County.
 Rocky Hill Spring, Fairfield, Somerset County.
 Sabattus Mineral Spring, Wales, Androscoggin County.
 Seal Rock Spring, Saco, York County.
 Sparkling Spring, Orrington, Penobscot County.
 Switzer Spring, Prospect, Waldo County.
 Thorndike Mineral Spring, Thorndike, Waldo County.
 Ticonic Spring, Winslow, Kennebec County.
 Underwood Spring, Falmouth Foreside, Cumberland County.
 Wawa Lithia Spring, Ogunquit, York County.
 White Sand Spring, Springvale, York County.

In addition to the springs given above, the following springs were reported by Peale,^a with analyses that were made at various dates between 1861 and 1879. It is not known whether all these springs are still in use, but none of them report sales.

American Chalybeate Spring, South Auburn, Androscoggin County.
 Auburn Mineral Spring, South Auburn, Androscoggin County.
 Boothbay Medicinal Spring, East Boothbay, Lincoln County.
 Ebeeme Spring.
 Fryeburg Spring, Fryeburg, Oxford County.
 Lake Auburn Mineral Spring, North Auburn, Androscoggin County.
 Lubec Saline Springs, head of Lubec Bay, Washington County.
 North Waterford Springs, northwest of Waterford village, Oxford County.
 Poland Silica Springs, South Poland, Androscoggin County.
 Rosierucian Springs, Rosierucian, Lincoln County.
 Samoset Mineral Springs, Nobleboro, Lincoln County.
 Scarboro Spring, Scarboro, Cumberland County.
 Summit Mineral Spring, Harrison, Cumberland County.
 West Bethel Spring, West Bethel station, Oxford County.

Analyses of some of the above were taken by Peale from Goodale's report.

^a Op. cit., pp. 15-16.

Origin of spring waters.—A common belief regarding the origin of spring waters is that most of them are derived from a distant source. Several spring owners have told the writer, with perfectly truthful intent, that the water in their springs came from the White Mountains, at least 40 or 50 miles away. Owners of flowing wells in Islesboro have stated their belief that the water of the wells has its source in mountains on the coast, several miles distant.

In some regions springs may have such an origin. Many of the waters of mineral springs in the West come long distances underground. In Maine, however, it is not known that a single spring or well obtains its supply at a distance of more than a mile from the place where the water emerges. The majority of spring waters enter gravel deposits on the surface of a hill and pass downward along the top of the bed rock or "hardpan" deposits until they find an easy point of emergence on the slope. In a few mineral springs the waters issue from joint cracks or from fissures in rock. These waters may come from a considerable depth, but as their temperature is generally about the normal temperature of the region, they are not believed to come from a greater depth than 100 feet below the surface.

Curative properties of spring waters.—Most owners of commercial springs publish numerous testimonials of wonderful cures wrought by the waters. From some advertisements it would appear that the water would cure nearly every known disease. It is not within the province of this report to discuss the medicinal value of waters, but a word of caution should be given. There are many reliable spring companies whose waters are all that is claimed for them. There are other companies who claim manifold cures which have never been made. It would be folly to expect any natural water to be a cure-all; but a few spring waters may be valuable for curative properties, which depend on the presence of certain elements or compounds. A summary of the medicinal value of mineral waters is given in a recent bulletin of the Bureau of Chemistry.^a Few of the Maine spring waters contain large amounts of dissolved solids, and therefore few can be called mineral waters in the true sense of the term. Most of them are merely pure natural waters, which are of value chiefly on account of the small amount of solid matter dissolved in them. It is by their purity and by their buoyant effect on the general health that they build up the system, rather than on account of any wonderful specific property inherent in the water.

^a Haywood, J. K., *Mineral waters of the United States*: Bull. Bur. Chemistry, No. 91. U. S. Dept. Agr., 1905, pp. 12-16. Compiled from Crook's *Mineral waters of the United States and Canada*, Schweitzer's *Mineral waters of Missouri*, Cohen's *System of physiologic therapeutics*, and other publications.

COLLECTING GALLERIES AND TUNNELS.

In many places, where a large amount of water is needed, infiltration or collecting galleries are constructed, generally in flood plains of rivers, where the water which saturates the deposits can be collected and pumped out. This method is especially adapted to public supplies for fair-sized towns. It has not been used in Maine, but there are a number of communities where it could probably be used to advantage.

WELLS.

GENERAL TYPES.

Open wells.—Open wells are ordinarily used for domestic purposes throughout the State. Wells of this type are generally 3 to 6 feet in diameter and from 10 to 50 feet in depth, the most common depth being about 30 feet. The depth is dependent on the distance to the water table and on the character of the material penetrated. Such wells are dug by hand if in surface deposits, or blasted if in rock. Dug wells are curbed with stone or bricks, generally uncemented. Sometimes open wells under 2 feet in diameter are bored with an auger; such wells are curbed with wooden curbs. Open wells are adapted principally to localities where the water is near the surface, especially where it occurs in small seeps, in clayey materials, and requires extensive storage space. Open wells should never be situated near sources of pollution.

Tubular wells.—This term is used in a general sense to describe all types of wells cased with iron pipe, or drilled in solid rock where casing is not necessary. In diameter they vary from $1\frac{1}{4}$ inches in some shallow driven wells to 15 inches or more in the largest tubular wells sunk for city water supplies. In soft unconsolidated deposits of sand and gravel which carry considerable water at shallow depths small pipes $1\frac{1}{4}$ to 4 inches in diameter, provided with points and screens, may be driven by hand or power. Such tubular wells are termed driven wells. In localities where the upper soil contains polluting matter driven wells are much safer than open wells, for, when driven some distance below the water table, they draw only from the lower part of the reservoir. Shallow tubular wells may be bored, or in soft deposits they may be sunk by the "jet process," which consists in forcing water down a small iron "jet pipe" inside the casing, the water and drillings rising between the two pipes. The casing sinks by its own weight or is forced down. Such wells are generally 2 to 4 inches in diameter. Tubular wells in rock or other hard material are commonly "drilled wells," sunk by lifting and dropping a heavy drill run by power. Tubular wells are cased with iron pipe in soft material and generally not cased in rock.

Connected wells.—Frequently two or more drilled wells are located near together and connected by exploding a charge of dynamite near

the bottom of the shallower one. Thus it is possible to pump several wells with a single pump. In a few places neighboring wells are connected naturally by joint cracks.

Combination wells.—A common form of well is the combination of dug and drilled or dug and driven well. Frequently when dug wells run dry the owner sinks a tubular well in the bottom, running the casing only to the bottom of the old open well, or only part way to the surface. As stated on page 54, such a combination well is unsafe.

METHODS OF OBTAINING WELL WATER.

Pumping.—In Maine there are few flowing wells, and in most wells the water must be raised artificially. The old-fashioned method of raising water is by the windlass, and in some parts of the State well sweeps are in common use. Such simple contrivances are only suitable for shallow open wells; in deep wells it is necessary to install a pump. This is also recommended in shallow wells, as it is easier of operation and the well can be covered to prevent entrance of animals, dust, organic matter, etc.

By far the great majority of wells in Maine are pumped by hand, and this method is in general fairly satisfactory when only a small

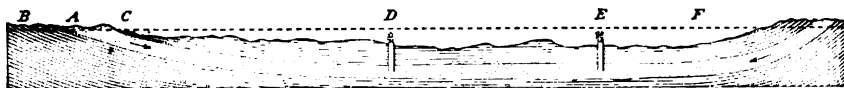


FIG. 3.—Diagram showing conditions under which flowing wells are commonly obtained in favorable regions. (After Chamberlin.) This sketch shows the contrast to conditions in Maine, illustrated in fig. 4. A, Porous stratum; B, C, impervious beds below and above A, acting as confining strata; F, height of water level in porous beds, or "head" of water; D, E, flowing wells supplied by water-filled bed A.

amount of water is required for domestic use. Hand pumps are either ordinary suction pumps, chain pumps, rotary pumps, or deep-well pumps. In the farming and summer-resort sections, however, windmills are common. They are inexpensive in comparison with the sums generally spent in drilling the well, and they save a great deal of manual labor, especially when the water is desired for stock. For public water supplies it is necessary to resort to some kind of power. Steam, hot air, and gasoline engines are in use. Many persons who own cottages on the coast or islands have these kinds of power, which give excellent service. There are in southern Maine about 30 wells pumped by steam, about 17 by gasoline engines, and about 20 by hot air. Several electric power pumps and two or three air lifts have been installed.

Artesian wells.—In many wells the water is under the pressure of a considerable head, forcing it to rise. Such wells are known as artesian wells. If the water rises enough to reach the surface, the wells are known as flowing artesian wells. The conditions under

which flows are normally obtained are described by Fuller,^a and the cause of the flow is illustrated in fig. 3. The pressure is due to the confinement of the water in inclosed beds beneath an impervious layer. The water enters the porous beds where they outcrop on the surface and flows downward beneath the impervious covering. When the latter is pierced by the well the water rises in consequence of the pressure due to the superincumbent water. Only a few flows of this type occur in Maine, however, and these are generally from surface deposits in very local basins.

Bayley, in his notes on the underground waters of Maine,^b gives the location of a few flowing wells in Maine, and several more were mentioned by Smith,^c in his Kittery-York report. A few more have been found by the writer. Most of these belong to the type illustrated in fig. 4, where the pressure is derived from systems of joint

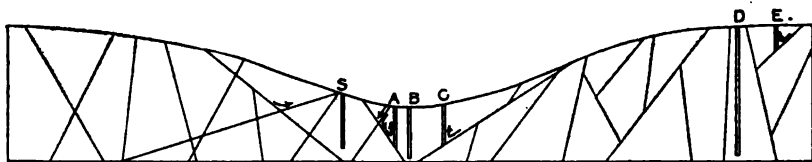


FIG. 4.—Diagram showing various conditions in drilled wells in Maine. A, C, conditions under which flowing wells may be obtained; B, D, S, conditions under which no water may be found; E, normal condition of obtaining water in drilled wells; A, conditions under which well may be polluted by surface drainage entering joint cracks near mouth of well.

cracks sloping from higher levels. A superficial coating of till or boulder clay generally prevents the water from reaching the surface by springs at higher points on the hill. The water penetrates downward along joint cracks and is tapped by a well lower down on the slope or near the bottom of the valley.

In all, 34 flowing wells are known in southern Maine. These are distributed as follows:

Flowing wells in southern Maine.

Androscoggin County.....	2
Cumberland County.....	11
Hancock County.....	3
Knox County.....	1
Penobscot County.....	2
Sagadahoc County.....	2
Somerset County.....	1
Waldo County.....	4
Washington County.....	1
York County.....	7

It will be noticed that flowing wells are most abundant in the southwest corner of the State. In the town of Greenville, several miles north of the area considered in this report, there is a group of

^a Fuller, M. L., Bull. U. S. Geol. Survey No. 319, 1908.

^b Bayley, W. S., Water-Supply Paper, U. S. Geol. Survey No. 114, 1905, p. 49.

^c Smith, G. O., Water-Supply Paper U. S. Geol. Survey No. 145, 1905, pp. 122-123.

flowing wells which are better than any elsewhere in Maine. These will be described in the forthcoming report on the underground waters of northern Maine. The highest flow due to artesian pressure in southern Maine is about 5 feet above the surface. In one well at Greenville, however, the water rises 20 feet above the surface.

LOCATION OF WELLS.^a

Factors to be considered.—The chief factors to be considered in choosing the best location for a well are (1) position of the water table, (2) accessibility and convenience, (3) direction of movement of ground water, (4) direction and movement of sewage, (5) points of most abundant water, and (6) possible sources of pollution.

Position of the water table.—The first factor is generally not important except in open or driven wells. These are generally shallow, because of the nature of their construction, and their cost is small. "On passing downward in porous or semiporous materials, such as those in which most open wells are located, a level is soon reached below which the ground is saturated with water (at least down to the first impervious stratum). This water body, or ground water, as it is called, has a definite upper surface, known as the water table, which conforms in general with the broader surface irregularities, but with the difference that the surface of the water table is flatter than that of the ground, being far below the ground on hilltops and cutting the surface in valleys." At a stream or swamp the water table reaches the surface, and the nearer to such natural features the well is situated the less will be its cost. The places where the water table is nearest the surface, however, are the most subject to pollution, and cheapness is often gained at the expense of safety.

Accessibility and convenience.—The location of any well is necessarily determined to a large extent by its nearness to the place where the water is to be used. Convenience often demands that open wells should be situated under houses or in barnyards, near privies or cesspools, or in other situations where they are subject to pollution, but it is always better to locate the well a few hundred feet away than to take such a risk.

Points of most abundant water.—In many places, especially on the uplands covered with bowlder clay, it is necessary to choose the location of open wells with reference to the relative abundance of water. In bowlder-clay deposits the best situation can not always be told in advance, as water in them occurs most commonly in somewhat porous channels not visible from the surface. When there is a choice between digging in bowlder clay or in gravel the latter should be chosen, especially if the gravel is underlain by bowlder clay, as

^a Considerable portions of this and the succeeding section are taken by permission from unpublished notes of M. L. Fuller. Literal excerpts are inclosed in quotation marks.

the water will penetrate downward until stopped by the more impervious bed, and will then be held in a sort of reservoir until tapped by a well or drained off laterally. On slopes the most abundant water is near the base of the slope. Generally there is abundant water in valley drift, but on the hills it occurs in smaller quantities.

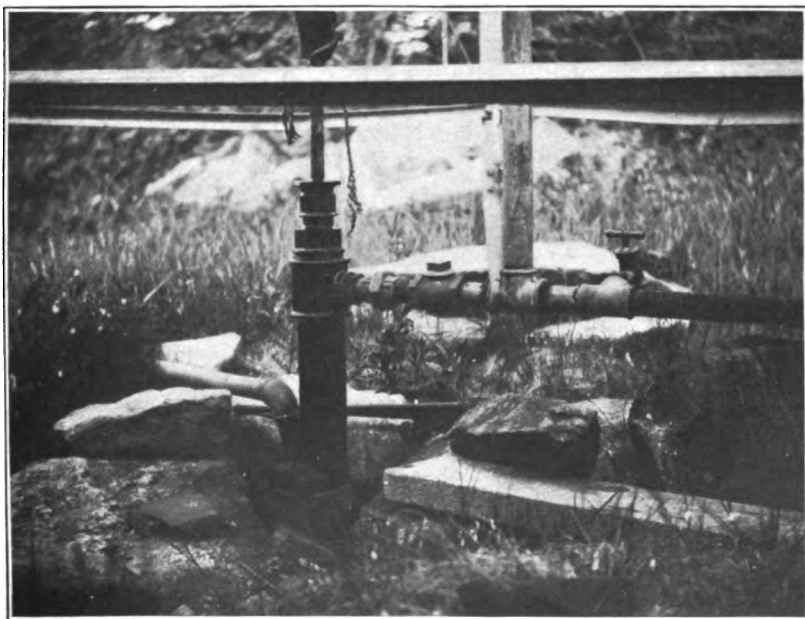
Direction of movement of ground water.—"The motion of ground water is always in the direction of steepest slope of the water table, and as this is likely to correspond with the direction of the surface slope the direction of motion of the ground water generally approximates that of the surface drainage." In drift deposits water moves from higher to lower levels. On hills it will move downward through the drift, along the top of the underlying rock. Exceptions are where till, clay, rock, or other relatively impervious formations dip in the opposite direction from the surface. In such cases the water will move downward from the surface along the top of the impervious bed. Wells which are intended to tap the reservoir of ground water should be situated at points toward which the water is moving, and these points must be determined by a study of the surrounding formations.

Sources of possible pollution.—Next to the question of abundance of water that of pollution is most important in a consideration of the location of wells. Purity or impurity of underground water is dependent on several factors. If porous drift extends downward indefinitely from the surface, opportunity is afforded for the downward penetration of polluting substances, but the water may sometimes be purified by filtering through sand. If the water-bearing bed is overlain by a covering of impervious rock or clay it is protected from pollution. The purity of water, even in deep wells, may be dependent on the tightness of the casing, both at the joints and at the connection with the pump. Some deep wells in Maine have been rendered dangerous by leaving the casing open at the top, thus affording entrance for surface drainage, small animals, etc. (See Pl. IX, B.) When wells are drilled into rock it is customary to drive the casing through the drift and a few feet into the ledge for the sake of protection, but where poor connection with the rock is made contamination often results. The purity of water is also dependent on the depth and kind of casing, as is explained on page 66.

"No well should be located where polluting matter has access to it. Such matter usually comes from cesspools or privies, slops thrown on the surface, backings from hen yards, pigpens, and barnyards, from manured fields, animals falling into the water, and filth thrown in through the open top or washed in through the plank coverings or leaky casings. The matter entering through the top can be kept out by cement, iron, or other impervious curbing. The entrance of material at the bottom of shallow wells can be prevented only



A. WELL AT COUNTY JAIL, WISCASSET.
Showing best method of protection from surface drainage.



B. WELL AT HERON ISLAND, SHOWING OPEN CASING.

PROTECTED AND UNPROTECTED WELLS.

by locating them beyond the reach of contamination. Where any of the polluting agents are present care should be taken to see that the well is located at least 100 feet away and on distinctly higher ground, so that both the surface drainage and the underground drainage—which generally moves in the same direction—will be away from it. On flat sands the wells should be at least 150 feet from any source of pollution. The importance of choosing a location safe from polluting influences is almost universally underestimated. Laying aside considerations of comfort and health, a safe well is nearly always, in the long run, the cheapest. Safety should invariably be made the first consideration instead of the last."

Location of deep wells.—The chief consideration in locating deep wells is to obtain a supply, slight differences in location seldom greatly affecting cost; moreover, owing to the prevailing use of casing in soft deposits, safety from ordinary pollution is insured. The occurrence of deep waters depends on the character and structure of the rocks far below the surface, and the well may usually be located independently of surface relief. In crystalline rocks and highly folded slates, such as are found in Maine, it is impossible to predict with certainty where a well should be drilled in order to be successful, although a study of the rocks by a geologist should afford some information regarding the probability of obtaining successful wells in various situations.

CHOICE OF A TYPE OF WELL.^a

Factors to be considered.—"The type of well is the first and perhaps the most important point to be decided when sinking for water is contemplated. Of the many types in use, including bored and driven wells, those sunk by the jet process, and those drilled by a rotary or percussion rig, each possesses one or more points especially qualifying it for use in some of the varying conditions encountered in drilling; on the other hand, each has some disadvantage which may disqualify it for use under certain circumstances. The chief factors which govern the selection of a type are usually the amount of water needed, the character of the materials to be penetrated, the depth to which the well must be sunk, the cost of sinking, and the safety of the resulting supply."

Amount of water obtained by different types.—Where the amount of water entering the well is small, it is obviously a distinct advantage to have a well of sufficient size to store water during the times when it is not in use. Open wells are best for this purpose, and this type also has the advantage of cutting a larger cross section

^a Considerable portions of this section are taken by permission from unpublished notes of M. L. Fuller.

of the water-bearing bed, and thus intercepting more water. In sands and other soft porous materials, which contain considerable water at slight depths, a driven well is desirable. Where water occurs in joint cracks, as in granite and slate, a well of large diameter offers greater chance of striking a seam of water than a well of small diameter. For all deep wells and for shallow wells in all but the softest materials drilled wells are recommended, as they are cheaper, more quickly put down, and safer than wells of the old-fashioned types.

Safety of different types.—Polluting matter finds entrance to a well in a number of ways. In dug wells it may enter through the crevices in the stone, brick, or wood curbing, or even through the pores of the brick itself; in bored wells it may enter through the uncemented joints of the tiling or cracks between the staves of the wooden curbing; and in drilled or driven wells it may enter through leaky joints or holes eaten in the iron casing by corrosive waters. In all types of open and curbed wells there is particular danger of surface wash. Open wells can be protected from this danger by proper curbing, but shallow wells of all kinds can be protected from underground pollution only by safe location. In a town or village, and even in close proximity to a farmhouse, few locations are safe, and hence drilled wells are almost universally the most desirable. These wells may become dangerous through leaky joints in a casing, through poor connection with the bed rock, through corroded casings, and through open tops. Where tiling is used for casing it may become so broken as to render the well dangerous. The danger of pollution in drilled wells can be remedied by proper construction.

“A particularly dangerous type of well—the more so because it is fancied to be secure—is a combination of the dug and drilled types. Because of the slight saving in expense, drilled wells are frequently sunk in the bottom of old dug wells, the casing often beginning at the bottom of the latter. Although the water encountered by the deep well may be perfectly pure at the start, contamination may take place almost immediately by the entrance, especially after rains, of seepage water into the open well and thence into the casing of the drilled well. The remedies are obvious. Either the casing should be carried to the surface of the outside ground, or at least above the highest level ever reached by the water, or the open well should be converted into a water-tight system by the application of a thick coating of cement over both sides and bottom.”

Types in use in Maine.—In this State dug wells greatly predominate in number over wells of all other types. Such wells are, however, relatively shallow; few of them exceed 50 feet in depth. For that reason few dug wells are listed in Professor Bayley's table

(pp. 242-259). Next to dug wells the most numerous are those sunk with an ordinary churn drill. Most of the wells described in this report are of this type, as they are by far the most practicable in regions of hard rock. Driven wells are abundant in Maine, but are of necessity confined to shallow depths and to valleys in which the sand and gravel deposits are very soft and easily penetrated by the well point. On account of their shallowness few of them are included in the table mentioned. There are very few bored wells in Maine, and these are all rather shallow.

DEPTH OF WELL.

OBJECT OF DEEP WELLS.

The depth to which a well is to be sunk is one of the chief questions to be decided, for on the depth are dependent both the type and the location. There may be at least three reasons why an owner should sink a deep well instead of a shallow one, viz, (1) to obtain an adequate supply, (2) to get a higher head, and (3) to get purer water.

RELATION OF ADEQUATE SUPPLIES TO DEPTH OF WELL.

Erroneous beliefs.—There seems to be a general belief that the amount of water increases with the depth, and that water may be found anywhere if only the well be drilled deep enough. Nothing, however, could be much farther from the truth. In surface deposits it is true that more water may be found with increasing depth as far as the gravel extends, but in the bed rock the occurrence of water follows different laws. The greater part of the water found in the earth came originally in the form of rain, and, as would be expected, the amount of water actually decreases rather than increases with great depth. Many rocks encountered by deep mines and wells, especially at depths below 1,000 feet, are entirely devoid of water.^a

Limiting depth of abundant water.—In an investigation of underground waters in crystalline rocks in Connecticut it was found that, although down to a depth of 200 feet the chances of striking water by deeper drilling are good, below 200 feet the chances decrease. The difference is due to the closeness of the joint cracks below that depth.^b Substantially the same conclusion has been reached for many rocks in Maine. Several wells more than 500 feet in depth, drilled in granite and gneiss, have obtained practically no water. One of the most experienced well drillers in Maine states that the

^aFuller, M. L., Total amount of free water in the earth's crust: Water-Supply Paper U. S. Geol. Survey No. 160, 1906, pp. 64-70.

^bEllis, E. E., Occurrence of water in crystalline rocks: Water-Supply Paper U. S. Geol. Survey No. 160, 1906, pp. 22-23.

average depth to which it is desirable to drill in granite is 185 feet, below which the chances decrease.

In many of the slate areas of the State, on the other hand, the maximum desirable depth seems not to have been reached, as wells 300 and even 400 feet deep report increasing supplies with increasing depth. As few slate wells more than 400 feet deep have been drilled, no statement can be made for greater depths, but it is believed that the cracks tend to close below 600 feet. As the occurrence of water in this State is uncertain the depth at which wells strike a sufficient volume of water is extremely variable and can not be predicted.

Conditions of greater abundance at depths.—It is true that under certain conditions the volume of water found may increase with the depth. Sand, gravel, and boulder clay, for instance, are dry down to the level of the water table, but below this level the amount of water increases until rock or some other impervious bed is reached. In some parts of Maine the surface deposit is clay, which contains very little water, but when this is penetrated gravels that contain an abundance of water are frequently found. Again, in rocks where the joints are open to great depths water may descend several hundred feet. Such is the case in some of the slate areas of Maine, where the deeper wells are the best.

Conditions of greater abundance near surface.—On the other hand, the quantity of water held in thick sand and gravel deposits is generally more than that in the rock or till below them. Water is more abundant in valley deposits than it is in the underlying rock. Where water-bearing sand rests upon clay the amount of water generally decreases as the clay is entered. Investigations have shown that in most rock wells the joint cracks are likely to be open near the surface and to diminish in size with increasing depth, and that if a depth of 200 to 500 feet or so, differing with the kind of rock, is reached without striking water it is generally cheaper and more satisfactory in all respects to start a new well. Usually the greater abundance of water in deep wells than in shallow ones is due to the fact that a greater number of water-bearing seams are encountered, and for this reason it is advisable to drill at least 200 feet if a sufficient supply is not obtained nearer the surface.

RELATION OF HEAD TO DEPTH OF WELL.

There is a general belief that the head as well as the volume increases with increase of depth. In a few wells such an increase was noted, for example, in the flowing wells at Greenville and in scattered wells elsewhere; but such cases are rare and are always due to chance local conditions which do not prevail over any wide area. In Maine flowing wells are exceptional and should not be hoped for. Sometimes the level of water in the well is raised by

going deeper, but this too is an accident. Most wells are drilled a few feet deeper than the water vein in order to form a reservoir for the water and whatever sediment it may contain.

RELATION OF PURITY OF WATER TO DEPTH OF WELL.

The prevailing idea in regard to purity, as in regard to volume and head, is that deep waters are best. This is generally true, for the reason that shallow waters are usually in unconsolidated deposits, and not being protected by impervious rocks or clay they are more likely to be polluted by surface drainage. A deep rock well is nearly always to be recommended where pure drinking water is desired.

When water is needed for industrial purposes the problem is somewhat different. While water from a depth is generally free from surface pollution, it often contains considerably more mineral matter in the form of incrusting constituents and is generally harder than most surface waters. In Maine, however, few waters are so hard as to prevent their use for laundries and boilers.

DEPTH OF WELLS IN SOUTHERN MAINE.

In the region covered by this report the drilled wells range in depth from 20 to more than 800 feet. Only a few, however, are more than 500 feet deep. Out of 500 wells in Professor Bayley's list (see pp. 242-259) which are more than 50 feet deep only six exceed 500 feet. In order to show the common depth of wells in various parts of southern Maine the following table has been prepared. Only drilled wells more than 50 feet deep are here considered.

Number of wells of different depths in southern Maine.

County.	Between 50 and 100 feet.	Between 100 and 200 feet.	Between 200 and 300 feet.	Between 300 and 400 feet.	Between 400 and 500 feet.	More than 500 feet.	Total number reported more than 50 feet.
Androscoggin.....	5	4	1	.....	.....	1	11
Cumberland.....	44	30	22	5	.....	2	103
Franklin.....	2	.....	.....	.....	.....	.....	2
Hancock.....	47	15	6	1	1	1	71
Kennebec.....	16	15	3	1	.....	1	38
Knox.....	7	15	7	3	.....	1	33
Lincoln.....	31	20	2	1	.....	.....	54
Oxford.....	4	4	.....	.....	.....	.....	8
Penobscot.....	39	13	4	1	1	.....	58
Somerset.....	5	1	.....	.....	.....	.....	6
Waldo.....	26	19	10	4	.....	.....	59
Washington.....	8	2	.....	1	1	.....	12
York.....	29	9	3	2	.....	.....	45
	283	147	58	19	3	6	500

DEPTH TO PRINCIPAL WATER SUPPLY.

In parts of the country where water occurs in definite beds it is possible to predict the depth at which it will be found by calculation

from knowledge of the lay of the rocks and the altitude of the surface. In Maine, however, the water occurs at no definite depth, and all statements as to the distance below the surface at which it will be found must be expressed only as probabilities. Professor Bayley, in compiling the well records, made an effort to obtain figures giving the depth of the principal water supply below the well mouth. It was possible to obtain these figures for more than half the wells; in the rest the depth to the water vein was not known by the owners.

In order to make comparison of the depths at which the principal supply was found in various parts of the State the following table has been prepared, giving the depths of the principal water bed as found in the several counties:

Number of wells in southern Maine obtaining principal water supply at stated depths.

County.	Between surface and 50 feet.	Between 50 and 100 feet.	Between 100 and 200 feet.	Between 200 and 300 feet.	Between 300 and 400 feet.	Below 400 feet.	Total number reported.
Androscoggin.....	1	3	1				5
Cumberland.....	6	19	14	9		1	49
Franklin.....		1					1
Hancock.....	11	35	7	1		1	55
Kennebec.....	4	7	6	1	1		19
Knox.....	1	10	11	1			23
Lincoln.....	6	20	8				34
Oxford.....	2	2					4
Penobscot.....	11	22	2	3		1	39
Sagadahoc.....	1	7	1	2			11
Somerset.....		2					2
Waldo.....	10	10	6	7	3		36
Washington.....	1	2			1		4
York.....	3	12	5	2	1		23
	57	152	61	26	6	3	305

By reference to the table it will be seen that nearly three times as many wells drilled more than 50 feet obtain their principal vein of water between 50 and 100 feet from the surface as those which obtain it within 50 feet of the surface. More wells obtain water between 100 and 200 feet than obtain it within 50 feet of the surface. The number encountering their principal water vein deeper than 200 feet, however, diminishes rapidly with each 100 feet of depth. Hence it can be said that the principal water vein may in the greater number of wells be looked for between 50 and 100 feet below the surface; but no one prospecting for water should begin to get discouraged unless he drills more than 200 feet without finding water.

Several exceptions can be made to the statements regarding the occurrence of the greatest number of water seams between 50 and 100 feet from the surface. For instance, it will be noticed that in Waldo County as many wells obtain water at depths less than 50 feet as between 50 and 100 feet, but that at the same time an equal number

obtain their largest supplies between 200 and 400 feet from the surface. Waldo County is largely made up of slate, which seems to hold plenty of water, and in that section the principal supply is just as likely as not to be obtained at depths greater than elsewhere. The statement is believed to hold true for Penobscot County also, although in that county shallow wells have met with such success that few have been drilled much below 100 feet. A further discussion of the probable maximum depth of water is given under the descriptions of the different rocks. (See pp. 29-38.)

DIAMETER OF WELL.

By far the most common diameter for drilled wells in this part of the country is 6 inches. Most drillers prefer to sink 6-inch holes, and the prices which they quote and those given in this report are for this size. For domestic use a sufficient supply of water can generally be obtained from a 6-inch well, and it does not seem desirable, except in particular cases, to go to the additional expense of sinking an 8-inch or 10-inch well. A 4-inch well is likely to be too small to give satisfaction, but a few of that diameter have been drilled.

Where a larger amount of water is needed, as in creameries, factories, hotels, etc., an 8-inch well is frequently sunk. Most of the wells drilled for the United States Government at forts along the coast are 8 inches in diameter, although a few of them are 6 inches. For a number of city water supplies, large hotels, etc., 10-inch or 12-inch wells have been drilled. These are expensive and ordinarily not desirable. Although theoretically they will yield a larger volume of water, it is not supposed that the amount of water stored in rocks in this State is sufficient to warrant many wells of this size. It is generally preferable to sink two or more smaller wells. In the early days of well drilling in Maine the business was not such an established one, and the wells were generally of odd sizes. For that reason many wells of 5-inch, 7-inch, 9-inch, and other diameters are reported.

Driven wells sunk for domestic purposes are generally from 1½ to 2½ inches in diameter, and this size suffices for most purposes. Larger wells are sometimes driven, however. In some of the city water-works batteries of 30 or more 2½-inch driven wells are used.

UNCERTAINTY OF RESULTS.^a

"The discovery of water by a given well in rocks of this State does not necessarily indicate that other wells drilled in the same neighborhood will likewise yield water. As a matter of fact, in several places dry wells and fairly successful wells are situated side by side. At North Haven, in Penobscot Bay, a well was drilled to a depth of 300

^aThe three paragraphs within quotation marks are from notes of Prof. W. S. Bayley.

feet without finding water; while a second well, less than 50 feet distant, encountered water at 60 feet under sufficient pressure to raise it within 14 feet of the surface. This well yields about 350 gallons a day.

"Again, at Palmyra, in Somerset County, three wells were drilled in slate. One was dry to a depth of 157 feet, at which depth the well was abandoned. A second, 70 feet distant, was drilled 80 feet, when it suddenly filled within 4 feet of the surface. It yields, however, but 25 to 50 gallons daily. A third well, 170 feet from the second one, struck water at 60 feet and now yields about 200 gallons daily.

"In the Kittery-York district a well on the road between York Harbor and York Beach yields 100 gallons an hour, the water vein at a depth of 25 feet giving a pressure sufficient to drive the water 2 feet above the surface. Near by, on Cape Neddick, only a few hundred yards from the flowing well, is another that was drilled to a considerable depth without encountering any water. A third well, at a slightly greater distance from the first, was drilled 87 feet, at which depth salt water was struck."

Fortunately, however, the risk of missing water is not great. The number of dry wells reported is small. The rocks in the southern part of the State (where most of the drilled wells are situated) are nearly all slaty, schistose, and much jointed rocks cut by granite and other igneous rocks. The foliation planes and joint cracks are numerous and closely spaced, so that a drill hole of even moderate length can scarcely avoid intersecting many of them. They afford abundant space for the storage of large quantities of water, but they yield it comparatively slowly.

An important consequence of the manner of storage of water in schistose and jointed rocks is that prophecies regarding the depth at which the water is to be found are valueless. In a gently folded region like Minnesota or Kansas an approximate estimate of the position of the porous water-bearing bed is usually possible. In areas of crystalline or metamorphic rocks like Maine, on the other hand, each well is an independent problem. The hole is sunk until it strikes a crevice or a group of crevices yielding sufficient water for the purpose needed, and the depth to which it must be sunk can not be foretold. In some wells water is encountered within 50 feet of the surface; in others only at much greater depths.

PROPORTION OF SUCCESSFUL WELLS.

An earnest effort has been made to obtain accurate information regarding the proportion of wells drilled which are successful. Such an estimate is difficult to obtain for several reasons. In the first place, most well drillers are naturally inclined to be optimistic and report few if any failures. Second, real failures are likely to be for-

gotten by residents of a community, and it is hard to get track of them. Third, there is no agreement between underground-water experts, well drillers, and owners as to what really constitutes a successful well. In several instances the United States Government has been known to abandon a well for the reason that its supply was only 10 to 20 gallons a minute. Large hotels have abandoned wells for the same reason. For ordinary domestic purposes, however, a well with this capacity is called very successful, and even 1 or 2 gallons a minute will usually suffice for a single family. If less water than this is obtained, the well is generally ranked as a failure.

As stated above, most well drillers report no failures. A few of the most experienced drillers report one or two wells in a hundred that do not yield sufficient water. In many instances there is a disagreement between the driller and the owner, owing to the fact that the well produced a fair amount of water when the vein was first pierced, but by the time the bill had been paid and the driller had moved to some other town the water gave out. Cases like this are due to the water occurring in pockets. For this reason some of the more experienced and reliable drillers will not leave a well until after waiting a sufficient time to determine whether the supply is likely to be permanent.

In the following table a successful well is considered as one that supplies enough water for ordinary domestic use, generally a gallon a minute. In compiling the table all wells more than 50 feet in depth in which the type of rock was known were considered. The unsuccessful wells include both those in which little water was found and those in which the water was of very inferior quality.

Proportion of successful wells in southern Maine.

Type of rock.	Number of successful wells.	Number of unsuccessful wells.	Total number of wells considered.	Percentage successful.
Granite.....	51	8	59	86
Gneiss.....	12	2	14	86
Slate.....	191	^a 23	214	88
Schist.....	34	3	37	92
Trap and greenstone.....	10	3	13	77
Complex.....	42	^b 6	48	87
	340	45	385	88

^a Including six wells ruined by entrance of sea water.

^b Including one well ruined by entrance of sea water.

It will be seen that, aside from the trap and greenstone wells, the percentage of successful wells was from 86 to 92, the average being 88. On account of the factors mentioned in the preceding paragraph, however, this is possibly somewhat overestimated. It is evident that trap and greenstone are the poorest rocks in this State in which to drill. If the six slate wells ruined by salt water should be included

with the successful wells, the percentage of probable success by drilling in slate would become 93, agreeing very well with the percentage for schist.

CAPACITY OF WELLS.

As very few wells in Maine are pumped by power, and as fewer of these are operated continuously or more than several hours at a time, it is difficult to make any definite generalization regarding the amount of water which they will yield. The best that can be done is to state the maximum and minimum amounts obtained and the most common reports of the yield in gallons a minute. Some of these reports are based on only a few minutes' pumping; in other cases the wells have been operated as a test for several hours or days continuously. Probably the majority of wells in Maine yield less than 5 gallons of water a minute. There are, however, many reports of yields as high as 10 or 20 gallons a minute, and a number of wells where more than 50 gallons a minute have been obtained for several hours continuously. A few yields of 100 to 200 gallons a minute are reported, but such high amounts can not be vouched for, as the exact conditions under which the test was made are unknown. One of the greatest factors in the reported capacity of the well is obviously the capacity of the pump used.

INCREASE IN YIELD.

In some wells the capacity increases with age. This is due to the fact that a newly drilled well contains at its bottom much fine material derived from the drilling, which tends to clog up the pores and water veins in the rock. As time passes this material is washed out, and the yield of the well becomes larger. Instances of such increases in yield are the well of the Penobscot Coal and Wharf Company at Searsport, that of the Maine Insane Hospital at Widows Island, and some wells in the town of Standish. In one well in Standish, drilled ten years ago, not more than half a gallon a minute could be obtained at first, but it has now increased in yield so that it can not be pumped dry.

DECREASE IN YIELD.

It is not uncommon for wells to decrease in yield some time after they are drilled. The change may begin to take place shortly after the well is first used, or it may not begin for years. In the former case it is generally due to the fact that pockets of water were struck, rather than permanent veins. In the latter case it may be due to several causes. Sometimes, when a drilled well is supplied largely by surface water, a single dry season will have a great effect on its yield. Some shallow drilled wells vary greatly according to the month of the year, but the best deep wells are supplied from sources

which can not be affected by changes in a single season, though sometimes a series of years in which the rainfall is below normal will affect these wells. In other wells the decrease in volume of water may be due simply to the gradual draining of the subterranean reservoir, and some such wells may never recover their original capacity. Usually when a newly drilled well has been carefully tested by the drillers and reported to yield several gallons of water a minute, and this capacity continues for several days, it is safe to regard the well as a success. It is never wise to let the driller depart until it is reasonably certain that the water does not come from pockets.

INTEREFFECT OF WELLS.

An interesting study could be made of the effect of neighboring wells upon one another, and such a study would be of great benefit to the inhabitants of a region and would increase the knowledge of conditions under which underground waters occur. The well at Foster's dyehouse at Portland is 140 feet deep in slate, and several water beds were penetrated. When a second well was drilled about 600 feet distant the water level in the dyehouse well was depressed about 3 feet.

In J. C. Rogers's granite quarry near Stonington two wells were drilled to depths of 94 and 279 feet. These wells are naturally connected by a joint crack about 60 feet from the surface. By pumping the 94-foot well water can be drawn from both. The capacity is 60 gallons a minute. The wells of the Southwest Harbor Water Company are situated 36 feet apart and are connected 90 feet from the surface.

At Dark Harbor, in the town of Islesboro, Charles Pendelton sunk a well to a depth of 88 feet. At a later date a well was sunk 16 feet distant, on the Allen property, and in half an hour from the time water was struck in the Allen well the yield of the Pendelton well diminished to such an extent that it would pump down so as to suck air. The Pendelton well was then deepened to 140 feet and encountered a large volume of water which supplied both wells. Water will now rise within 5 feet of the surface in both, but the greater part of the water in Allen's well is supplied from Pendelton's. The rock is much broken up at this place, and in the Pendelton well the drill was very nearly lost in a crack at a depth of about 80 feet.

USES OF UNDERGROUND WATER.

The prevailing use of both well and spring waters in Maine is for drinking and other domestic purposes and for watering stock. Spring and well waters are used for the public supplies of many villages, and well water is used in boilers of locomotives or manufacturing estab-

ishments, there being little water in Maine that gives too much scale for this purpose. Several creameries use water for cooling cream, and pulp mills use it for cooling acid. In granite quarries, especially on the islands, the water problem is an important one, and in several places well drilling has met with success. In addition to the ordinary uses of water, certain spring waters have value as "mineral waters." They are put on the market and shipped to distant centers, or the springs are made sites for summer hotels, thus contributing to the health of the country and to the wealth of the State.

COST OF WELL DRILLING.

The cost is necessarily an important factor in the sinking of wells. It varies with the locality, the kind of rock, and other conditions. For a rock well under 30 feet in depth the cost of drilled and open wells is about the same. A shallow well in drift may be cheaper if dug than if drilled, but in general drilled wells are the cheapest if they are carried down more than a few feet. Of all types the cheapest is the driven well, and this type is recommended wherever practicable. Such wells can be sunk to moderate depths through sand, fine gravel, and clay for \$10 to \$20.

The cost of drilled wells is very variable, depending on the locality and the kind of rock. In Aroostook County, where the rocks are rather soft slate, the cost is only \$2 a foot in surface deposits and \$1 in ledge, cased to rock and the casing furnished. Near Bangor, where the rock is slate, the charge is \$3 per foot for the first 50 feet, \$4 for the second 50 feet, and \$5 for every foot below 100. This price includes the casing. A well 247 feet deep at Bangor cost \$940; the windmill cost \$66 and the pump \$45. At other places in Penobscot County the price is \$3 a foot straight, and in some towns it is less. In Lincoln County, in the area of complex, the common charge is \$3.50 a foot, but some wells have been drilled for less. On account of the expense of drilling, it is possible that the price in this section may be raised. At Bucksport, in Hancock County, a well 308 feet in depth cost \$1,540 and a steam pumping plant cost \$360.

Wells on the islands cost more than those on the mainland. In Lincoln County island wells cost \$6 a foot. In Hancock County, where the rock is largely granite, the cost is generally \$4 on the mainland and \$5 on the islands. Most drillers charge \$6 in granite. Blasted wells, only a few feet deep, are \$4 a foot. On Widows Island, near North Haven, a well 109 feet deep cost \$525; and a gasoline engine and pump \$177. In Islesboro, where more drilling has been done than in any town in Maine, the charge is \$3 a foot, but drillers will not set up their machines without an agreement to drill at least 50 feet.

In Washington County, where little drilling has been done, the cost is \$6 a foot. At Portland and vicinity it is \$4 a foot in drift and

\$4 to \$6 in rock. A 151-foot well on Cape Elizabeth cost \$752, the pump \$246, and a 40,000-gallon tank \$900. A well 120 feet deep on Peaks Island cost \$450 and a hot-air engine and deep-well pump \$400. On Diamond Island a 96-foot well cost \$500. In York County the price is generally about \$6 a foot. In the vicinity of Winthrop, Kennebec County, where the rock is slate, the price has been raised from \$3 to \$5 a foot. The lower price ought to be sufficient here, as it is in most of the slate areas.

NOTES ON WELL DRILLING IN MAINE.

GENERAL STATEMENT.

As drilled wells are becoming more and more necessary in Maine, and as well drilling constitutes a considerable industry, which benefits the community at large, it seems important to include here a brief discussion of certain aspects of drilling that are not understood or appreciated by everyone.

RELATION TO KIND OF ROCK.

Speed of drilling.—The speed of drilling in Maine varies from a few inches to 30 feet a day, depending on the kind of machine, character of rock, abundance of joint cracks, etc.

With a good machine an experienced man can drill a 6-inch hole an average distance of 5 feet a day. In granite, however, 5 feet is usually the maximum daily performance, and sometimes a very hard, fine-grained phase of the rock is struck in which the drill will not go more than 1 foot a day. These hard portions of the rock are generally aplite dikes. In the slates of southern Maine the speed of drilling varies with the nature of the rock, ranging as a rule from 2 to 14 feet a day, though in southern Aroostook County, where the slate is softer, it averages 20 feet. One driller claims to have sunk a slate well 44 feet deep in eight hours, but this record is exceptional. Quartz seams in slate retard the speed of the drill.

A well on House Island, near Portland, drilled in metamorphic slate or schist, is said to have been deepened 35 feet in one night. In the 196-foot well of the Warren Water Company the average speed was 3 feet and the fastest 9 feet a day. As a rule, the finer the grain of the rock the harder it is to drill. In schist and metamorphic slates the drilling is much slower where they stand on edge than where they are flat. Pl. X, B, shows a dike of granite in slate, illustrating how differences in type of rock may affect the speed of drilling.

Effect of joint cracks.—Where joint cracks are parallel to the surface, or nearly so, they seldom affect the ease of drilling. Where they dip at a high angle, especially in the harder rocks, drilling becomes less easy. Frequently tools become stuck in the rock and

much time and labor are wasted in recovering them. At other times the bit will strike the hard, smooth surface of the rock and glance off to one side, making a crooked hole. In such cases stones and occasionally scraps of soft iron are thrown into the hole and blasted with dynamite, breaking up the rock so as to give the drill a hold on it. Sometimes it is necessary to abandon such wells and make a second attempt. The slates of Penobscot County have few troublesome joints, and in them drilling is relatively easy. Most of the crooked holes have been sunk by inexperienced drillers. In some wells in granite and other hard rock the drilling is reported to "sharpen the drill." Other types of rocks cut the drill to pieces.

CASING FOR DRILLED WELLS.

Methods of casing.—Properly constructed drilled wells are so cased that absolutely no surface water can enter the well. It is rarely necessary or desirable to case rock wells far into the rock, but the casing should always be driven through the surface deposits and several feet into the bed rock. If a tight joint is not made with the bed rock an opportunity is furnished for polluted surface water to enter between the casing and the rock. In Government wells the casing is generally driven 12 feet into the ledge. If the bed rock is within a few feet of the surface, it is well to dig around the outside of the casing and cement it firmly to the rock.

Pl. IX, *B*, shows a type of well which is seen far too often. The top of the casing is not even attached firmly to the pump or covered over, but is open in such a way that surface drainage or small animals might easily enter it. The owners of such unprotected wells are advised to close the pipes at the surface. Pls. V, *B*, and IX, *A*, show the proper method of protecting the well by a coating of cement.

Kind of casing.—Galvanized iron pipe is commonly used for casing wells, and as a rule is serviceable. In some places in Maine, however, the galvanized iron imparts a very disagreeable taste to the water, making it unfit for drinking. The water, through some acid property, attacks the pipe, eating pin holes through it, and the well has to be abandoned or recased. Generally ordinary iron pipe is free from this disadvantage, but in places trouble is experienced with this also. Block-tin pipe, though expensive, is as a rule little acted on by water. A well at New Harbor, in Lincoln County, was first cased with galvanized iron, but the taste of the water was too strong. A change was then made to a block-tin pipe, but the water ate pin holes in it and finally wooden pipe had to be put in. An example of the trouble caused by the use of galvanized iron is furnished by the experience of the Rumford Falls Water and Power Company. (See p. 184.)



A. SLATY ROCK ALONG THE COAST, CHRISTMAS COVE.

Showing nature of rock in which poor water of that vicinity is found.



B. OUTCROP OF ROCK ALONG COAST, FORTUNE ROCK, BIDDEFORD.

Showing alternation of hard and soft layers.

INJURY TO WELLS BY SEA WATER.

At a number of places along the Maine coast, especially on the islands, ocean water has entered through crevices in the rock and mingled with the well water to such an extent that the well has had to be abandoned. As a rule trouble with salt water occurs where the rock is slate. In a few places, however, salt-water wells have been obtained in granite. A well owned by Mrs. Kiesel in the town of Islesboro obtained good water at 181 feet from the surface, but drilling was continued, and at 220 feet salt water was encountered. The well was filled with Portland cement to a depth of about 200 feet from the top, the sea water being thus shut out, and the water was reported of good quality in 1906.

In other wells fresh water is first obtained, but after continued pumping the water becomes salt. Such was the case in the Thorp well on Greenings Island, off Mount Desert, which rises and falls with the tide. The water in the R. A. Foss well in Scarboro, 200 feet deep and situated 200 or 300 feet from salt water, was good for a month, but then became salty.

An interesting well is that of the Consolidated Electric Light Company of Maine, at Portland. In 1887 this well was drilled 136 feet and obtained good water. Like the Kiesel well, it was deepened in the hope of getting a larger supply, and salt water was encountered. The total depth of the well was 204 feet. In 1890 it was plugged. The plugging shut off much of the magnesium carbonate and calcium carbonate content of the water and increased the sodium chloride considerably.

An example of the entrance of sea water occurs in the town of Sorrento, which lies on a small neck jutting out from the mainland opposite Sullivan. The slate on this neck is very hard, dense, and fine grained and breaks up on the weathered outcrop into small angular blocks a few inches square. The strike and dip of the strata are variable. In some places the cleavage agrees with the stratification, but in others it does not. Clay 5 to 10 feet thick overlies the slate along the shore, and it is probable that this would prevent the accumulation of much water on the surface of the peninsula. The outcrops along the coast show that the rock is deeply fissured by wave action, some vertical cracks a foot or more across running in for a distance of several feet. As some of the fissures are inclined toward the south, it is probable that the sea water enters the rock on the north side of the peninsula and makes its way far below the surface into wells. This will explain why the only two wells drilled on the peninsula were failures, so far as finding fresh water was concerned. Pl. X, A, gives an idea of the character of rock along the coast in which salt water is sometimes found.

SHOOTING WELLS.

In many parts of the country, and particularly in the oil regions, it has been the custom for many years to explode heavy charges of nitroglycerin in the bottom of deep rock wells. This practice increases the yield of many of the wells enormously, greater amounts either of oil or of water being obtained. The increase in yield is due to the fracturing of the rock by the force of the explosion, cracks being formed in which the liquid can move more freely through the rock toward the well.

In many regions water wells have been "shot" with success, and this leads to the question whether that method might not be used in Maine. A few experiments have been tried by certain drillers, who have exploded charges at the bottom of deep wells. It is found that in a hard rock like granite the explosion will form small cracks, and in a few instances water has entered from a near-by seam and supplied the well. Softer rocks, however, like slate and schist, are little broken up, and definite cracks are not formed; hence it is hardly worth while to shoot wells in these rocks. A crooked well drilled at Bath, 90 feet in depth, was shot with 75 pounds of dynamite, but it did no good. This well is situated in the area of complex.

Dr. Charles G. Weld, of North Haven, has two successful wells 12 feet apart, 114 and 140 feet deep. These wells were connected by exploding torpedoes at a depth of 114 feet in both of them.

A number of crooked holes have been straightened by shooting. A prominent well driller has informed the writer that an explosion of dynamite in a crooked hole is frequently much better than reaming it. Generally 75 to 150 pounds of dynamite are used. The explosion makes very little shock, but sometimes scatters water and pebbles several hundred feet from the well.

DATE OF DRILLING.

Study of the well records given in Professor Bayley's table (pp. 242-259) shows that nearly half the wells in southern Maine have been sunk within the last decade. In the farming regions of the State drilling has been largely a necessity, and for that reason considerable was done as early as the eighties, and the number of wells drilled annually does not seem to have increased materially since then. But in the summer-resort regions, which are mostly situated on or near the coast, the greater part of the drilling has been done since 1899. There was some drilling in these sections as early as 1890, but during the early nineties few wells were put down on account of the general industrial depression of the country. The following table has been compiled from the well records in order to give an idea of the relative number of wells drilled in each decade:

Number of wells drilled in southern Maine, by decades.

Before 1880.....	2
1880-1889.....	72
1890-1899.....	133
1900-1906.....	183
	390

The total is less than the number of drilled wells reported in the table, for the reason that many owners or drillers have failed to report the year in which their wells were drilled.

PUBLIC SUPPLIES.

GENERAL STATEMENT.

Classification of sources.—Public water supplies in Maine are drawn in part from surface sources, including rivers, streams, and ponds, and in part from springs and wells. Some of the surface sources are so situated that the water is of good quality. Springs are good when they are properly situated, and wells are always desirable if they are deep and properly cased. Several towns use more than one of these sources, and some communities have changed from surface to underground supplies or vice versa.

Ownership of public water systems.—A preliminary list of the cities and villages possessing water-supply systems was given by W. S. Bayley in 1905,^a the lists being obtained through correspondence. During the summer of 1906 several months of field work was done by the writer, and the lists were enlarged considerably. The following paragraphs in quotation marks are from the notes of Professor Bayley:

"As a result of the investigations, the water systems of the State fall into three groups with reference to ownership. The first and most numerous group is that owned by incorporated stock companies; a second group embraces those owned by private parties; and a third group includes those owned by cities or town corporations or by water districts. The third group embraces the smallest number of systems, but they are the largest, since they include the systems supplying the largest communities. As a rule the service is managed directly by the corporate officers in villages, or by water commissioners in cities.

"In recent years another method of management has come into vogue. When a community has reached the limit of its borrowing capacity, or is too small to warrant the construction of an independent system, a water district is formed, usually embracing two or more distinct municipalities, but perhaps including only a portion of a single

^a Water-Supply Paper U. S. Geol. Survey No. 114, 1905, pp. 40-47.

one. The affairs of the district are managed by a board of trustees chosen by the officers of the municipalities interested. The water rates are established by these trustees, and the profits arising from the operation of the plant, after paying running expenses and providing a certain sum for the maintenance of a sinking fund, are turned into the treasuries of the municipalities.

History.—"Until recently nearly all the public supplies of Maine were obtained from surface sources, such as lakes and streams. In recent years, however, because of the increasing difficulty of finding uncontaminated surface supplies, there has been a tendency to utilize the underground resources wherever possible. Many villages situated in the rural districts have always used spring water, which is conveyed to them in pipes, and in many places small groups of houses are supplied in the same way, but these systems have usually been owned by private parties and not by public corporations. In late years there has been a rapid increase in the number of public systems furnishing spring water. It is plain, however, that since springs are limited in capacity, the size and number of communities which can depend on them for their public supply must likewise be limited. When this limit is reached recourse must be had to wells, if an underground supply is desired, or to lakes if suitable ones are within reach."

Comparative use of various sources.—With reference to their sources of supply the communities have been grouped under three heads—those obtaining water from springs, those using wells, and those supplied by rivers, streams, and lakes. Nearly all the large cities use lake water, as this is found to be more satisfactory than river water, because the great quantity of waste matter discharged into the streams from factories and the numerous settlements along their banks often renders them unfit for domestic use. Of the larger communities, only Bangor, Biddeford, and Saco continue to draw their supplies from streams. Augusta, Waterville, and Rumford Falls have recently changed from rivers to lakes, and Brunswick from a lake to wells. Several others of the smaller communities are agitating a change from rivers to lakes or wells, and the trend of opinion in Bangor is to the effect that Penobscot River must soon be abandoned.

The accompanying lists contain 151 names of communities that are receiving water distributed through pipes and delivered in houses. Of these, 29 obtain their supply from springs, 13 from wells, and 109 from surface sources. The names of several of these communities are duplicated, as a few receive their water from two sources, and others are at present changing from one source to another. Exclusive of duplicates, the number of communities purchasing water distributed through pipes is 148. The lists give the most important data that have been collected with

respect to the water-supply systems in the southern part of the State. They are believed to contain the names of practically all the communities enjoying water service, but a few communities may have been overlooked.

Relative merits of sources.—The choice between a surface and an underground source of supply for any community must be controlled by several factors. In the first place, not all communities are so situated that the most desirable source of supply is near at hand. In certain districts it is almost impossible to obtain a good water supply. In others it is necessary to use streams which are contaminated by sewage and manufacturing wastes from towns situated farther upstream. Many of these communities may be situated in places where no adequate underground supply can be obtained, and such is especially the case with large cities for the reason that the yield of wells always has a maximum limit. Where the quantity of water from wells is not sufficient it is generally necessary to resort to surface sources, even though the water may not be as pure as desired. In all cases the quality of the water should be considered first, as on this depends the health of the people who drink it. Another feature which must be considered in certain districts is the amount of mineral matter contained in the water. Where the supply is desired largely for boilers or manufacturing purposes the amount of contained lime and other dissolved matter should be small, but in Maine this factor is generally not high enough to render the water detrimental.

COMMUNITIES USING WELL SUPPLIES.

There are 13 communities in southern Maine which obtain their public water supplies from driven or drilled wells. All these supplies are believed to be of excellent quality. The communities are enumerated in the following table, and the owners, sources, and methods of distribution are given for convenience of reference. A full description of these water supplies is given under the county headings.

Water systems in southern Maine using wells as sources of public supply.

No.	Community.	County.	Population.	Owner.
1	Brunswick.....	Cumberland.....	5,210	Brunswick and Topsham water district.
2	Castine.....	Hancock.....	936	Castine Water Co.
3	Cushing Island.....	Cumberland.....		Francis Cushing.
4	Great Diamond Island.....	do.....	450	Diamond Island Association.
5	East Northport.....	Waldo.....	150	Mountain Spring Water Co.
6	Hancock Point.....	Hancock.....	100	Village corporation.
7	Peaks Island.....	Cumberland.....	500	C. E. Rounds Water Co.
8	Rumford Falls.....	Oxford.....	2,585	Rumford Falls Light & Water Co.
9	Sanford.....	York.....	2,000	Sanford Light and Water Co.
10	Southwest Harbor.....	Hancock.....	720	Southwest Harbor Water Co.
11	Topsham.....	Sagadahoc.....		Brunswick and Topsham water district.
12	Warren.....	Knox.....	2,069	Warren Water Co.
13	Winthrop.....	Kennebec.....		Winthrop Cold Spring Water Co.

Water systems in southern Maine using wells as sources of public supply—Continued.

No.	Source.	Quality.	Method of distribution.
1	50 driven wells.....	Soft.....	Pumped into reservoir.
2	Drilled wells.....	do.....	Reservoir.
3	do.....	do.....	Tank on hill.
4	do.....	Hard.....	Pumped into reservoir.
5	Drilled well and springs.....	Soft.....	Do.
6	Old mine shaft.....	do.....	Do.
7	Drilled wells.....	do.....	Pumped to standpipe.
8	75 driven wells.....	Soft.....	Reservoir.
9	Dug and driven well.....	do.....	Pumped to standpipe.
10	2 drilled wells.....	Soft.....	Pumped to reservoir.
11	50 driven wells.....	do.....	Pumped by windmill and gasoline engine to reservoir.
12	Drilled well.....	do.....	Pumped to reservoir by windmills.
13	Drilled wells.....	Hard.....	

COMMUNITIES USING SPRING SUPPLIES.

More than twice as many villages draw their water supply from springs as from wells. These, 29 in number, are enumerated in the following table, and the owners, sources, and methods of distribution of water are given for convenience of reference. A full description of these supplies will be found under the appropriate county descriptions.

Water systems in southern Maine obtaining public supplies from springs.

No.	Community.	County.	Population.	Owner.
1	Addison Point.....	Washington.....	150	Addison Point Aqueduct Co.
2	Bingham.....	Somerset.....	800	J. J. Lander et al.
3	Bolsters Mills.....	Cumberland.....		Alfred R. Clark.
4	Brooks.....	Waldo.....	300	Consolidated Water Co., of New Hampshire.
5	Casco.....	Cumberland.....	100	S. O. Hancock.
6	Cherryfield.....	Washington.....		Several small systems.
7	East Northport.....	Waldo.....	3,000	Norton Spring Water Co.
8	Farmington Falls.....	Franklin.....	200	Stock company.
9	Friendship.....	Knox.....	300	Friendship Water Co.
10	Hallowell.....	Kennebec.....	2,714	City of Hallowell.
11	Harrington.....	Washington.....	1,200	Two aqueduct companies.
12	Lamoine.....	Hancock.....		Cold Spring Water Co.
13	Lisbon Center.....	Androscoggin.....	100	
14	Lisbon Falls.....	do.....	1,585	Sylvester Aqueduct Co.
15	Lubec.....	Washington.....		Town of Lubec.
16	Milbridge.....	do.....		Milbridge Water Co.
17	North New Portland.....	Somerset.....	360	
18	North Waterboro.....	York.....	230	Chase & Johnson.
19	Orrington.....	Penobscot.....		
20	Paris Hill.....	Oxford.....	251	Paris Hill Water Co.
21	Ridlonville.....	do.....	143	Shaw-Ridlon Land Co.
22	Searsmont.....	Waldo.....		L. B. Cobb & Son.
23	Skowhegan.....	Somerset.....	6,000	Several aqueduct companies.
24	Stratton.....	Franklin.....		
25	Union.....	Knox.....	1,000	Union Water Co.
26	Vienna.....	Kennebec.....		
27	Winthrop.....	do.....		Several well systems.
28	Yarmouth.....	Cumberland.....		Town of Yarmouth.
29	Yarmouthville.....	do.....	1,000	Do.

Water systems in southern Maine obtaining public supplies from springs—Continued.

No.	Source.	Quality.	Method of distribution.
1	Spring 1 mile distant.....	Soft.....	Direct pressure.
2	Several springs.....	do.....	Do.
3	2 springs near by.....	do.....	Do.
4	Spring 2 miles distant.....	"Hard".....	Do.
5	.....	Soft.....	.....
6	Spring near by.....	do.....	Do.
7	Well and springs.....	do.....	Reservoir.
8	Spring near by.....	do.....	Direct pressure.
9	Spring.....	do.....	From tank pumped by windmill.
10	Spring on Winthrop Hill.....	do.....	Direct pressure.
11	Spring not far from town.....	do.....	Do.
12	Spring.....	do.....	Pumped to reservoir by windmill.
13	do.....	.....	.....
14	2 springs.....	Soft.....	Direct pressure.
15	Marston's spring.....	do.....	Direct to standpipe.
16	2 springs.....	do.....	Direct pressure.
17	Spring.....	.....	.....
18	.....	Soft.....	Do.
19	Whidden Spring.....	.....	.....
20	Crocker Hill Springs.....	Soft.....	Do.
21	Spring.....	.....	.....
22	Dyer's spring.....	.....	Do.
23	Spring.....	Soft.....	Do.
24	do.....	.....	.....
25	2 springs $\frac{1}{2}$ miles distant.....	Soft.....	Do.
26	Spring.....	.....	.....
27	Spring and wells.....	Soft.....	Do.
28	Forest Paper Co.'s spring.....	do.....	Standpipe.
29	do.....	do.....	Do.

COMMUNITIES USING SURFACE SUPPLIES.

Of the 148 communities having public water supplies in the southern part of the State, 109 use water from lakes, ponds, rivers, or brooks. In a description of underground-water supplies it is important for purposes of comparison to record what communities are using surface sources. Moreover, towns sometimes change from surface to underground sources or vice versa. For these reasons a table of the communities using surface sources is appended.

Water systems in southern Maine obtaining public supplies from surface sources.

No.	Community.	County.	Population.	Owner.	Source.
1	Astleon.....	Hancock.....	50	.....	Jordans Pond.
2	Auburn.....	Androscoggin.....	12,951	Auburn Aqueduct Co.....	Lake Auburn.
3	Augusta.....	Kennebec.....	11,683	.....	Lake Cobbossee-contee.
4	Bangor.....	Penobscot.....	21,850	Public Works Co.....	Penobscot River.
5	Bar Harbor.....	Hancock.....	2,500	Bar Harbor Water Co.....	Eagle Lake.
6	Bath.....	Sagadahoc.....	10,477	Maine Water Co.....	Lake Nequasset.
7	Bayville.....	Lincoln.....	57	.....	Adams Pond.
8	Belfast.....	Waldo.....	4,615	Belfast Water Co.....	Little River.
9	Belgrade.....	Kennebec.....	.....	Belgrade Water Co.....	Belgrade Lake.
10	Benton.....	do.....	.....	Kennebec water district.....	China Lake.
11	Bethel.....	Oxford.....	722	Bethel Water Co.....	Chapman Brook.
12	Biddeford.....	York.....	16,145	Biddeford and Saco Water Co.....	Saco River.
13	Boothbay Harbor.....	Lincoln.....	2,000	.....	Adams Pond.
14	Brewer.....	Penobscot.....	4,835	Public Works Co., Bangor.....	Penobscot River.
15	Buckfield.....	Oxford.....	379	.....	South Pond.
16	Bucksport.....	Hancock.....	.....	Bucksport Water Co.....	Silver Lake.
17	Camden.....	Knox.....	.....	Camden and Rockland Water Co.....	Mirror Lake.
18	Cape Elizabeth.....	Cumberland.....	.....	Portland water commissioners.....	Sebago Lake.

Water systems in southern Maine obtaining public supplies from surface sources—Cont'd.

No.	Community.	County.	Popula- tion.	Owner	Source.
19	Cape Neddick.....	York.....	164	York Shore Water Co.....	Chase Pond.
20	Cape Porpoise.....	do.....	420	Mousam Water Co.....	Monson River.
21	Chisholms Mills.....	Franklin.....	800	Livermore Falls Water Co.	Moose Hill Lake.
22	Damariscotta.....	Lincoln.....		Twin Village Water Co.....	Little Pond.
23	Dexter.....	Penobscot.....			Dexter Pond.
24	East Lamaine.....	Hancock.....	170		Blunts Pond.
25	Eastport.....	Washington.....	5,311	Eastport Water Co.....	Boydens Pond.
26	Ellsworth.....	Hancock.....	4,297	Ellsworth Water Co.....	Branch Pond Stream.
27	Ellsworth Falls.....	do.....	400	do.....	Do.
28	Fairfield.....	Somerset.....	3,800	Kennebec water district...	China Lake.
29	Falmouth Fore- side.	Cumberland.....	175		Sebago Lake.
30	Farmingdale.....	Kennebec.....		Gardiner water district...	Cobbosseecontee Stream.
31	Farmington.....	Franklin.....	1,200		Varnum Pond.
32	Freeport.....	Cumberland.....	759	Freeport waterworks.....	Frost Galley Brook.
33	Fryeburg.....	Oxford.....	550	Fryeburg Water Co.....	Two brooks in Con- way, N. H.
34	Gardiner.....	Kennebec.....	5,501	Gardiner water district...	Cobbosseecontee Stream.
35	Glencove.....	Knox.....	117		Mirror Lake.
36	Gorham.....	Cumberland.....		Gorham Water Co.....	Sebago Lake.
37	Great Works.....	Penobscot.....			Penobscot River.
38	Hallowell.....	Kennebec.....	2,714		Cobbosseecontee Stream.
39	Hartland.....	Somerset.....		Linn Woolen Co.....	Sebasticook River.
40	Hastings.....	Oxford.....	200		Brook.
41	Hebron.....	do.....	500	Hebron Water Co.....	Halls Pond.
42	Hulls Cove.....	Hancock.....	177	Bar Harbor Water Co.....	Eagle Lake.
43	Kennebunkport.....	York.....	2,100	Mousam Water Co.....	Branch Brook.
44	Kennebunk.....	do.....		do.....	Do.
45	Kennebunk Beach.....	do.....	170	do.....	Do.
46	Kennebunk Land- ing.	do.....		do.....	Do.
47	Kittery.....	do.....	1,500	Agamenticus Water Co....	Folly Pond.
48	Kittery Point.....	do.....	400		Do.
49	Kingfield.....	Franklin.....	700	Kingfield Water Co.....	Outlet Tufts Pond.
50	Lamoine Beach.....		100		Blunts Pond.
51	Lewiston.....	Androscoggin.....	23,780	Lewiston water commis- sioners.	Lake Auburn.
52	Livermore Falls.....	do.....	1,250	Livermore Falls Water Co.	Moose Hill Lake.
53	Machias.....	Washington.....		Machias Water Co.....	Machias River.
54	Madison.....	Somerset.....	1,850	Madison Water Co.....	Kennebec River.
55	Mechanic Falls.....	Androscoggin.....	1,500	Mechanic Falls Water Co.	Waterhouse Brook.
56	Milford.....	Penobscot.....		Public Works Co., Bangor.	Penobscot River.
57	New Castle.....	Lincoln.....		Twin Village Water Co.....	Little Pond.
58	North Berwick.....	York.....			Stream supplied by springs.
59	Newport.....	Penobscot.....		Newport Water Co.....	Pillsbury Pond.
60	North Vassalboro.....	Kennebec.....	850		China Lake.
61	Northeast Harbor.....	Hancock.....	350		Hodlock's Lower Pond.
62	Norway.....	Oxford.....	2,034	Norway Water Co.....	Norway Lake.
63	Oakland.....	Kennebec.....	2,500	Oakland Water Co.....	Messalonskee Lake.
64	Ocean Bluff.....	York.....	375	Mousam Water Co.....	Branch Brook.
65	Ogunquit.....	do.....		do.....	Do.
66	Old Orchard.....	do.....	1,000	Biddeford and Saco Wa- ter Co.	Saco River.
67	Oldtown.....	Penobscot.....	5,763	Public Works Co., Bangor.	Penobscot River.
68	Orono.....	do.....	3,257	do.....	Do.
69	Perry.....	Washington.....		Eastport Water Co.....	Boydens Lake.
70	Phillips.....	Franklin.....	674	Moore & Garing.....	Mount Blue Pond.
71	Pittsfield.....	Somerset.....	2,208	Pittsfield waterworks.....	Sebasticook River.
72	Portland.....	Cumberland.....	50,145	Portland water commis- sioners.	Sebago Lake.
73	Rangeley.....	Franklin.....	563		Cascade Brook.
74	Randolph.....	Kennebec.....		Gardiner water district...	Cobbosseecontee Stream.
75	Richmond.....	Sagadahoc.....		Richmond waterworks.....	Kennebec River.
76	Rockland.....	Knox.....	8,180	Camden and Rockland Water Co.	Mirror Lake.
77	Do.....	do.....	8,180	Rockland Water Co.....	Lake Chickawauke.
78	Rockport.....	do.....	2,314	Camden and Rockland Water Co.	Mirror Lake.
79	Rockville.....	do.....	150		Do.
80	Saco.....	York.....	6,122	Biddeford and Saco Wa- ter Co.	Saco River.
81	Seal Harbor.....	Hancock.....	250	Seal Harbor Water Sup- ply Co.	Jordans Pond.

Water systems in southern Maine obtaining public supplies from surface sources—Cont'd.

No.	Community.	County.	Population.	Owner.	Source.
82	Searsport.....	Waldo.....	.....	.....	Half Moon Pond.
83	Sorrento.....	Hancock.....	100	Estate of Frank Jones.....	Long Pond.
84	South Paris.....	Oxford.....	1,457	Norway Water Co.....	Norway Lake.
85	South Portland.....	Cumberland.....	6,287	Portland water commissioners.	Sebago Lake.
86	South West Harbor.....	Hancock.....	720	South West Harbor Water Co.	Long Pond.
87	South Berwick.....	York.....	1,000	South Berwick Water Co.	Two Brooks.
88	Skowhegan.....	Somerset.....	4,266	Skowhegan waterworks.....	Brook 1 mile from village (in part).
89	Southport.....	Lincoln.....	.....	.....	Adams Pond.
90	Springvale.....	York.....	2,000	Springvale Aqueduct Co.	Littlefields Pond.
91	Squirrel Island.....	Lincoln.....	50	.....	Adams Pond.
92	Stockton Springs.....	Waldo.....	.....	.....	Half Moon Pond.
93	Strong.....	Franklin.....	600	Strong Water Co.....	Outlet of Day Mountain Pond.
94	Sullivan.....	Hancock.....	.....	.....	Long Pond.
95	Thomaston.....	Knox.....	2,600	Camden and Rockland Water Co.	Mirror Lake.
96	Veazie.....	Penobscot.....	.....	Public Works Co., Bangor.	Penobscot River.
97	Waterville.....	Kennebec.....	10,000	Kennebec water district.....	China Lake.
98	Westbrook.....	Cumberland.....	7,283	Portland water commissioners.	Sebago Lake.
99	Wells Beach.....	York.....	.....	Mousam Water Co.....	Branch Brook.
100	West Kennebunk.....	do.....	350	do.....	Do.
101	Wilton.....	Franklin.....	2,000	.....	Varnums Pond.
102	Winnegance.....	Sagadahoc.....	156	.....	Lake Nequasset.
103	Winslow.....	Kennebec.....	.....	Kennebec water district.....	China Lake.
104	Winter Harbor.....	Hancock.....	600	Grindstone Neck Water Co.	Birch Harbor Pond.
105	Winterport.....	Waldo.....	.....	.....	West Branch Lowes Brook.
106	Woolwich.....	Sagadahoc.....	.....	Maine Water Co.....	Lake Nequasset.
107	York.....	York.....	.....	York Shore Water Co.....	Chase Lake.
108	York Corner.....	do.....	250	.....	Do.
109	York Beach.....	do.....	500	York Shore Water Co.....	Do.

COMPOSITION OF THE UNDERGROUND WATERS.

GENERAL EXPLANATIONS.

Classes of analyses.—The analyses reported in the table on pages 77-87 include all chemical analyses (mineral analyses) of Maine well and spring waters that could be obtained. They may be grouped in four classes:

(1) "Field assays," or approximate analyses of half-pint samples made in the field by F. G. Clapp, G. C. Matson, and B. L. Johnson, of the United States Geological Survey.

(2) Analyses of 1-gallon samples shipped to Prof. F. C. Robinson, at Bowdoin College, Brunswick, Me., and analyzed by him.

(3) Analyses made by W. W. Skinner, of the United States Department of Agriculture, in connection with cooperative work between the Geological Survey and the Bureau of Chemistry.

(4) Analyses made by other persons.

The first group of analyses are designated "assays" for the reason that they were made with a field outfit to obtain a general idea of the character of the water.^a They do not pretend to be refined analyses, and are published only because it was impracticable, on account of

^a Leighton, M. O., Field assay of water: Water-Supply Paper U. S. Geol. Survey No. 151, 1905.

expense, to make more than 70 analyses of the second group, and only 10 of the third group had been made.

In order that the reader may form a graphic idea of the proportions of the different ions in various rocks and localities, the analyses of the second group have been plotted on Pls. IV, VI, and VIII.

Recomputation of analyses.—The analyses made by the United States Geological Survey are uniformly reported in ionic form and parts per million. Analyses obtained from miscellaneous sources, however, were originally given as parts per million, parts per 100,000, or grains per gallon, and were mostly reported in the form of the chemical compounds in which the minerals are supposed to exist. Chemical research shows that there is no certainty that the elements are combined in this form, the compounds given in most analyses being mainly theoretical. For this reason all analyses which were not expressed according to the standard method when received by the writer were recomputed into ions and parts per million, and they are expressed in this form in the table.

Omission of sanitary analyses.—Few sanitary analyses are included in this report, although hundreds of them have been made by the state board of health and other analysts. The reason for this omission is that sanitary analyses record only those constituents of a water which may be present by reason of its pollution or the entrance of organic matter in other ways. The substances reported in a mineral analysis of water, however, are with few exceptions, derived from materials dissolved from rocks or surface deposits, and are at all times nearly the same for a given well or spring; varying only with the amount of rainfall, the height of the water level, or, in the case of a well, with the age of the well. The substances reported in a sanitary analysis are chlorine, ammonia, nitrites, and nitrates—substances that are formed during the decay of organic matter, and consequently are present in soils, sewage, and other wastes. The amount of these impurities varies from time to time according to local conditions.

Much has been written in scientific journals regarding the value or worthlessness of a sanitary analysis. The best chemists of the world now agree that it is of value only when considered in connection with other matters, such as the location of the well or spring with reference to sources of pollution. As the present paper is designed for permanent reference, and as sanitary analyses of any water vary from time to time, only a few such analyses are given here. Others may be found in the annual reports of the state board of health, to which interested persons are referred.

DETAILS.

Tables.—The following tables contain nearly 300 analyses of well and spring waters. The well table is subdivided according to the kind of rock penetrated.

Analyses of well waters in southern Maine.

[Parts per million.]

WELLS IN GRANITE.

No.	Locality.	Owner.	Type.	Depth (feet).	Total solids.	Organic and volatile matter.	Silica (SiO ₂).	Iron and aluminum oxides (FeO ₃ +Al ₂ O ₃).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Bicarbonate radicle (HCO ₃).	Sulphate radicle (SO ₄).	Chlorine (Cl).	Total hardness as CaCO ₃ .	Analysis.
1	Androscoggin County:																	
2	Lisbon.	R. A. Small.	Drilled.	(?)	4	948	18.17	0	0.51	19	2.2	7.9	0.5	107	tr.	14		H
3	South Poland.	Chas. Gould and W. F. Trask.	do.					0							13			H
4	Cumberland County:																	
5	Bridgeport.	F. H. Abbott.	(?)	(?)	0			0							0		8.6	F
6	Do.	F. P. Bennett.	Drilled.	(?)	0			0							0		24	F
7	Do.	J. K. Martin.	do.	125	206	74	31.1	2.8		29	7.6	9.6	6.9	44	tr.	4.7	9.6	F
8	Do.	Granville Morrison.	do.	72	11			0							tr.	9		F
9	Do.	Unknown.	do.	125	45			0							tr.	9		F
10	South Freeport.	J. H. Lee.	do.	108	39			tr.							(?)			F
11	Hancock County:																	F
12	Eden.	Edw. Morrell.	do.	87	6			0							99	tr.	14	F
13	Greening's Island, North-east Harbor.	J. G. Thorp.	do.	88		5.2	8.5	1.1		1.1	1.8	11	1.7		15	23		R
14	North Sullivan.	C. H. Abbot.	do.	37	0			0							tr.	24		F
15	Do.	John M. Blaisdell.	do.	25	0	196	8.3	4.7		37	4.3	26	5.6		tr.	102		F
16	Do.	Crabtree & Haney.	do.	51	23			0.5							15	15		F
17	Do.	Do.	do.	51	23			2.1		62	3.4	63	3.7		16	140		F
18	Stonington.	Samuel W. Goss.	do.	67	26	67	12.5	1							tr.	58		F
19	Do.	R. B. Judkins.	do.	67	156	48									15	32	53	H
20	Crotch Island, Stonington.	Ryan-Parker Construction Co.	do.	300	4			1							125	70		F
21	The Settlement, Stonington.	J. C. Rogers.	do.	933	0			0							(?)	14		F
22	Do.	Do.	do.	279	0	136	19	2.0		29	3.4	13	1.9		(?)	17		R
23	Kennebec County: Augusta.	Chas. F. Tittetts.	Blasted.	30	42	18									26	4		R
24	Knox County: Vinalhaven.	Glue factory.	Drilled.	230	4,056	1,046	194.7	1.4		404	131	465	140		122	1,790		R
25	Lincoln County:																	
26	Bristol.	J. W. P. Gowdy.	do.	52	0			0							33	tr.		F
27	Damariscotta.	Mrs. G. C. Chapman.	do.	87	0			0							123	58		F
28	Damariscotta Mills.	G. W. Waltz.	do.	64	129	29	23.8	2.5		18	2.9	13	5.8		tr.	14		F
29	Pemaquid Beach.	C. A. Sprout.	do.	45	919	272	13.7	7.1		45	14	134	40		46	334		R
30	Pemaquid Harbor.	C. A. Farrin.	Blasted.	25	22			5							6	32		F
31	Waldoboro.	R. L. Benner.	Drilled.	56				0							(?)	4		F
32	Do.	Miss E. F. Genthner.	do.	56	419	100	10.9	3.5		57	9.0	30	13		36	57		R

^a F. Field assay by F. G. Clapp, G. C. Matson, or B. L. Johnson; R. F. C. Robinson, analyst; H. Sanitary analysis by state board of health.

^b Includes lithium (Li), trace; carbonate radicle (CO₃), 36. ("Apollo water.")

^c SO₄, less than 35 parts per million.

Analyses of well waters in southern Maine—Continued.

WELLS IN SLATE.

No.	Locality.	Owner.	Type.	Depth (feet).	Color.	Total solids.	Organic and volatile matter.	Silica (SiO ₂).	Iron and aluminum (Fe ₂ O ₃ + Al ₂ O ₃).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Bicarbonate radicle (HCO ₃).	Sulphate radicle (SO ₄).	Chlorine (Cl).	Total hardness as CaCO ₃ .	Analyst.
29	Cumberland County:																		
30	Cape Cottage.	Amos Miller	Drilled.	115		140	22	9.0	0.9	0	43	2.4	11	3.8		15	18		
31	Gorham.	Dan Cressy	do.	66		20									765	(m)	39		
32	Great Diamond Island.	Diamond Island Ass'n	do.	120		120	14	16	.8	0	15	6.4	10	3.0	45	22	10		
33	Portland.	do.	do.	86		0									45	22	10		
34	Free Point.	W. D. Pennell	do.	67		88	30	8.8	2.0	0	7.0	4.5	7.3	1.5	61	22	10		
35	Peaks Island.	Brown Hill Water Co.	do.	70		0									61	22	10		
36	do.	C. W. T. Goding	do.	135		163	40	4.7		0	27	0.4	18		25	25	27		
37	Portland.	Mrs. F. Leavor	do.	164		52	22			0					170	64	185		
38	do.	Mrs. F. Leavor	do.	164		8				0					160	83	106		
39	do.	Chas. A. Brown.	do.	106		160	48			0					160	83	106		
40	do.	E. I. Burrows.	do.	204		2,008				0									
41	do.	Consolidated Electric Light Co.	do.																
42	do.	James Cunningham.	do.	35		142	26												
43	do.	M. R. Griffith.	do.	178		644	192												
44	do.	do.	do.	505		177	0.5	11		2.5	13	4.3	38	11		6.8	212	172	
45	do.	Maane General Hospital	do.	161		610	54												
46	do.	John T. Palmer	do.	40		140	90												
47	do.	G. J. Thurston.	do.	200		7				0	12	4.7	12	17	76	38	15	46	
48	Scarboro.	H. J. Libby estate.	do.	200		145	13	12.1	2.6						101	32	13		
49	do.	do.	do.	86		0				tr.	24	7.8			76	36	13		
50	Standish.	R. W. E. Shaw.	do.	216		344	60	135	tr.	0	24	3.0	10	3.7	76	36	13		
51	Westbrook.	Haskell Silk Co.	do.	216		6		19	2.6	0	24	3.0	10	3.7	76	36	13		
52	do.	Rufus Jordan.	do.	216		129	18			0					98	36	13		
53	do.	do.	do.	307		5				0									
54	do.	J. H. Rimes.	do.																
55	Hancock County:																		
56	Bucksport.	Eastern Maine Conference Seminary.	do.	308		116	9.6	15	1.8		26	3.6	18	2.2		22	6.5		
57	do.	do.	do.																
58	Hancock.	Jeremiah Straton.	Open.	Few		53	5.6	8.9	1.1		9	1.4	7.6	1.4		9	9.2		
59	Orland.	Mrs. A. W. Emerson.	Drilled.	65		109	10	15	1.0		16	2.9	6.7	2.3		11	12		
60	do.	Mrs. A. W. Hutchins.	do.	42		9				0.1					28	10	4		
61	Kennebec County:																		
62	Farmingdale.	H. M. Hodgdon.	do.	107		170	96												
63	do.	Tibbels & Sawyer.	do.	80		33				1.7	39	0.9	30	11		20	46		
64	Gardner.	Chas. Hopkins	do.	34		298	40	20	1.4						37	21	04		

63	Sidney	G. F. Bowman.	do.	96	6	0	0	0	0	37	tr.	121	F	
64	Winslow	J. L. Dean.	do.	65	4	0	0	0	0	153	tr.	7.5	F	
65	Do.	Will Glidden.	do.	30	11	0	0	0	0	49		1.9	F	
66	Do.	J. F. Howard.	Open.	(?)	60	0	0	0	0	135	(m)	10	F	
67	Winthrop	C. M. Bailey Sons & Co.	Drilled.	3074	227	20	16	2.0	57	6.3	27	5	R	
68	Do.	do.	do.	3074	0	0	0	0	0	95		7.5	R	
69	Do.	Frank S. Wood.	do.	175	217	0	0	0.35	0	99	tr.	4.7	F	
70	Winthrop Center.	Mrs. H. J. Bailey	do.	200	0	0	0	0	0	35	tr.	11	(g)	
71	Knox County.	The Roxmont.	Open.	16									F	
72	Penobscot County.	Banger House.	Drilled.	290	4	834	150	17	1.0	519	52	55	F	
73	Bangor.	do.	do.	290	0	150	0	0	0	(?)	63	58	F	
74	Do.	Jos. E. Buckley.	do.	30	0	0	0	0	0	146	tr.	15	(g)	
75	Do.	Eastern Maine Insane Hospital.	do.	425	0	0	0	0	0				F	
76	Do.	High School.	do.	217	0	491	124		0.02				F	
77	Do.	do.	do.	217	0	180	37	10	1.1	224	42	46	(A)	
78	Do.	do.	do.	217	0	441	62	47	ftr.	10	18	50	(g)	
79	Do.	do.	do.	217	0	436	190	0	0	82	15	33	R	
80	Do.	H. F. Hanson	do.	35	0	0	0	0	0	20	72	229	F	
81	Do.	F. L. Jones.	do.	2474	0	0	0	0	0	121	145	2.7	F	
82	Do.	Maline Creamery Co.	do.	120	0	0	0	0	0	20	72	229	F	
83	Do.	do.	do.	120	0	0	0	0	0	121	145	2.7	(A)	
84	Do.	do.	do.	180	0	86	21	6.7	0.7	20.1	5.7	4.0	R	
85	Do.	Morse & Co.	do.	255	0	61	0	0	0	160	(m)	5.9	F	
86	Do.	Palm Street School	do.	72	0	256	61	0	0.2	38	24	24	(A)	
87	Do.	do.	do.	72	0	233	58	18.1	ftr.	8.4	44	11	(g)	
88	Do.	Penobscot County court-house.	do.	2004	0	242	40	0	0	44	11	11	(g)	
89	Do.	do.	do.	2004	0	0	0	0	0				F	
90	Do.	Union Square School.	do.	203	0	439	103	0	0	221	(m)	76	(g)	
91	Do.	do.	do.	203	0	0	0	0	0	54	54	288	F	
92	Charleston	A. A. Dorthy.	do.	38	0	0	0	0	0	266	(m)	50	F	
93	Do.	J. H. Higgins.	do.	38	0	0	0	0	0	157	tr.	6.6	F	
94	Do.	C. H. Scribner.	do.	33	0	93	16	7	1.2	18	6.8	3.1	1.4	F
95	Do.	do.	do.	16	0	0	0	0	0	199	tr.	14	F	
96	Cortina	Wm. Pitcher.	do.	27	0	0	0	0	0	317	tr.	32	F	
97	East Newport.	L. D. Babb.	Drilled.	714	67	424	92	0	0.5	104	tr.	11	188	F
98	Do.	J. P. Chadbourne.	do.	63	57	474	158	0	0	64	64	80	320	F
99	Do.	J. B. Chadbourne.	do.	57	0	74	11	12	1.5	80	80	320	F	
100	Do.	Mrs. A. J. Bragg.	do.	103	69	0	0	0	0	6	6	4.6	F	
101	Hamptden.	Cyrus Moulton.	do.	75+	20	0	0	0	0	35	(m)	10	10	F
102	Do.	C. L. Philbrick.	do.	50	15	0	0	0	0	109	(m)	25	25	F
103	Do.	Town well.	do.	28	2	0	0	0	0	56	0	20	20	F
104	Hamptden Corners	S. E. Harris.	Blasted	55	44	0	0	0	0	110	(m)	52	52	F
105	North Dixmont.	do.	Drilled.	55	44	0	0	0	0	316	40	112	112	F
106	Orrington.	Archie Harding.	do.	50	4	165	37	8.3	2.1	73	7.1	8.7	8.7	F
106	Stetson.	F. P. Abbott.	do.	50	4	165	37	8.3	2.1	73	7.1	8.7	8.7	R

m SO₄ less than 35 parts per million.

† Includes some suspended clay.

‡ Al₂O₃.

§ When drilled hardness 140.

|| With suspended clay.

* Chas. Harrington.

† Carbonate radicle (CO₂), 140.

‡ Ora W. Knight.

§ E. L. Robinson.

a Carbonate radicle (CO₂), 40.

b Well plugged at 145 feet; salt water.

c Carbonate radicle (CO₂), 84.

d E. L. Robinson.

Analyses of well waters in southern Maine—Continued.

WELLS IN SLATE—Continued.

No.	Locality.	Owner.	Type.	Depth (feet).	Color.	Total solids.	Organic and volatile matter.	Silica (SiO ₂).	Iron and aluminum oxides (Fe ₂ O ₃ + Al ₂ O ₃).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Bicarbonate radicle (HCO ₃).	Sulphate radicle (SO ₄).	Chlorine (Cl).	Total hardness as CaCO ₃ .	Analyst.	
07	Sagadahoc County: Bowdoinham.	E. C. McFarlane.			45					0					134	(a)	35			
08	Somerset County: Norridgewock.	G. C. Haynes.	Drilled.	26	0					0					35	tr.	3.5		35	F
09	Pittsfield.	W. R. Hunnewell.	Dug.	47		56	16											5	35	
10	Do	F. J. Taylor.	do.	26		406	74											48	188	
11	Waldo County: Belmont.	Horsea Cheney.	Drilled	187		138	9.5	17	2.5		23	6.4	15	6.1			14	5		R
12	Cape Jellison	Northern Maine	do.			104	25	12	tr.	10	18	6.2				tr.	7	(c)	(d)	
13	Islesboro	R. A. Bolt.	do.	398		0				0						tr.	33		F	
14	Do	Islesboro Land and Improvement Co.	do.	149	0					0						149	tr.	22	F	
15	Do	M. E. Lewis.	do.	150		145				0						155	tr.	11	85	
16	Do	H. T. Sloan.	do.	198		0				tr.						104	0	7.7		F
17	Jackson.	E. E. Morton.	do.	45	22					tr.	20	4.2				76	0	30	(/)	F
18	Kladders Point.	Northern Maine	do.			146	24	16	tr.	10						0	8		(d)	
19	Monroe.	R. R. Co.	do.	60		164	50	13	1.2	0.5	37	6.3	7	2.7		14	8.5		R	
20	Do	Nathan Stearns.	do.	60	22					2						95	(a)	8.7		F
21	Seaport.	do	do.	3294	102											62	(a)	65		F
22	Do	Northern Maine Seaport	do.								28.4	5.1	21	6.2		28	22	7	(e)	R
23	Do	W. E. Grinnell.	do.	100		102	11	21	3	5.2	8.5	2.7				tr.				
24	Troy.	R. R. Co.				101	13	21	tr.	0.5										
25	Winterport.	Chas. Harmon.	Drilled.	40	22					tr.						112	(a)	20		F
26	Do	S. Chase.	do.	57		17				tr.						0	14	40		F
27	Do	J. K. Downs.	do.	40	17					tr.						90	tr.	7.4		F
28	Stockton Springs.	Northern Maine Seaport	do.			104	25	9.5	tr.	9.1	10	1.5				tr.	10	(a)	(d)	
29	Do	R. R. Co.	do.																	
30	York County: Cutts Island, Kittery.	Roland Thaxter.	do.	75	80					1.5						39		29		F
31	Do.	do.	do.	75		209	15	11	3.2		46.8	13	27	8.7		14	40		R	
32	Kittery Point.	Horsea Mitchell.	do.	60	6					0						03		44		F
33	Ogunquit.	Chas. C. Hoyt estate.	do.	65		169	11	19	3.2		34.1	0.7	13	7.9		18	20		R	

WELLS IN AREAS OF COMPLEX.

132	Knox County:	Nelson Mullen.....	Drilled.....	10.....	0.....	0.....	0.....	217 (a)	20	F
133	North Haven.....	Ray G. A. Strong.....	do.....	4.....	0.....	0.....	0.....	88 (a)	40	F
134	Vinalhaven.....	Warren Water Co.....	do.....	200.....	0.....	0.....	0.....	42 tr.	3.3	F
Lincoln County:										
135	Christmas Cove.....	Everett Westcott.....	do.....	100.....	107.....	13.....	10.....	6.6.....	4.4	17
136	Do.....	E. F. Wilder.....	do.....	180.....	22.....	12.....	1.9.....	5.2.....	33	14
137	Coopers Mills.....	Chas. H. Ashford.....	do.....	65.....	240.....	4.....	7.3.....	2.6.....	31	61
138	Do.....	S. E. Hopkins.....	do.....	46.....	13.....	25.....	0.....	0.....	21	28
139	East Boothbay.....	Hudson Bros.....	do.....	120.....	25.....	13.....	0.....	0.....	96 tr.	24
140	Do.....	Frank Rice.....	do.....	75.....	13.....	188.....	26.....	17.....	102	15
141	Do.....	Do.....	do.....	75.....	13.....	188.....	26.....	17.....	68	42
142	Heron Island.....	Wm. C. Darnon.....	do.....	119.....	225.....	34.....	25.....	8.5.....	16	17
143	Ocean Point.....	L. J. Crooker.....	do.....	360.....	25.....	96.....	9.3.....	8.4.....	44	33
144	Do.....	Do.....	do.....	360.....	25.....	96.....	9.3.....	8.4.....	11 tr.	12
145	Pemaquid Point.....	W. A. Elliott.....	do.....	51.....	0.....	115.....	0.....	0.....	148 tr.	14
146	Do.....	M. F. Macdonald.....	do.....	22.....	5.....	70.....	0.....	0.....	238	34
147	Wiscasset.....	Customs House.....	do.....	70.....	7.....	68.....	0.....	0.....	228	49
148	Do.....	J. P. Turber.....	do.....	68.....	8.....	154.....	0.....	0.....	228	77
149	Do.....	Wiscasset Fall.....	do.....	154.....	301.....	18.....	21.....	1.3.....	138	31
Sagadahoc County:										
150	Bath.....	H. Langdon.....	do.....	26.....	0.....	0.....	0.....	0.....	40	44
151	Do.....	Roller Pushing Works.....	do.....	180.....	69.....	123.....	28.....	16.....	105 tr.	40
152	Woolwich.....	F. W. Carleton.....	do.....	98.....	123.....	28.....	16.....	1.9.....	98	915
Waldo County:										
153	East Northport.....	Northport Mountain Spring Co.....	do.....	162.....	0.....	145.....	39.....	0.....	13	17
154	Do.....	Mrs. Mark Mandall.....	do.....	64.....	234.....	82.....	0.....	0.....	0.....	6.4
H.....										
H.....										
H.....										

WELLS IN IGNEOUS ROCKS OTHER THAN GRANITE.¹

155	Knox County:	F. S. Mead.....	Drilled.....	126.....	2,057.....	355.....	22.....	2.2.....	515	52	209	7.2	125	965	R
156	Do.....	G. W. Wheelwright.....	do.....	180.....	90.....	0.8.....	10.....	0.....	30	1.2	8.9	0.7	4.9	13	R
Washington County:															
157	Eastport.....	Seacoast Canning Co.....	do.....	408.....	25.....	414.....	42.....	46.....	0	108	11	30	214	70	F
158	Do.....	Do.....	do.....	408.....	25.....	414.....	42.....	46.....	0	108	11	30	214	70	R
159	Jonesport.....	Do.....	do.....	384.....	22.....	414.....	42.....	46.....	0.5	0	0	0	28	47	F
160	York County: Cutts Island, Kittery.....	John Thaxter.....	Open.....	6.....	22.....	22.....	0.....	0.....	0	0	0	0	70 tr.	19	F

^aSO₄ less than 35 parts per million.^bAlO₃.^cTemporary, 34; total, 80.^fTemporary, 35.^gTemporary, 25; total, 59.^hTemporary, 25; total, 55.ⁱWells 155, 156, 100 are in trap; 157, 158 in greenstone; 159 in diorite.

Analyses of well waters in southern Maine—Continued.

WELLS IN CLAY.

No.	Locality.	Owner.	Type.	Depth (feet).	Color.	Total solids.	Organic and volatile matter.	Silica (SiO ₂).	Iron and aluminum oxides (Fe ₂ O ₃ +Al ₂ O ₃).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Bicarbonate residue (HCO ₃).	Sulphate radicle (SO ₄).	Chlorine (Cl).	Total hardness as CaCO ₃ .	Analyst.
161	Cumberland County: Scarborough.	Jno. H. Leavitt.	Dug.	194	0					0					58	(a)	27		F
162	Franklin County: Farmington.	Warren Ladd.	do.	58	30					0					27	tr.	40		F
163	Hancock County: Brooksville.		do.	16	100					0					43	0	5.2		F
164	Do.		do.	14±	7					0					116	53	85		F
165	Kennebec County: Vassalboro.	Geo. C. Gardner.	do.	16	2					0					70	(a)	12		F
166	Washington County: Lubec.		do.	30±	148					0					67	47	14		F
167	York County: North Kennebunkport.	Edwin Dennett.	do.	5						0					127	tr.	40		F

WELLS IN TILL (BOWLDER CLAY).

168	Cumberland County: Portland.	Unknown.	Dug.	12	33					tr.					40	0	8.6		F
169	Hancock County: Eden.	do.	do.	16	0					0					16	tr.	10		F
170	Orland.	do.	do.	22	0					0					29	(a)	19		F
171	Sorrento.	T. N. Nickerson.	do.	8	38					0					29		11		F
173	Penobscot County: Orono.	N. W. Page.	do.	54	0					0					77	tr.	34		F
174	Washington County: Jonesboro.		do.	7						0					34	tr.	16		F

WELLS IN SAND AND GRAVEL.

175	Androscoggin County: Auburn.	E. H. Libby.	Open.	27	0					0					31	tr.	4.9		F
176	Mechanic Falls.		Driven.	35	0					0					10	tr.	3.2		F
177	Cumberland County: Brunswick.	Brunswick and Topsham Water District.	do.	25	55			12	0.2		4.2	1.8	8.9			6.5	4.0	26	F

178	Do	do	55	11	0.2	3.9	2.3	7.3	11	4.0	26
179	Do	do	42							16	22
180	do	Public supply								15	
181	do	West Broadway	5		0				23	tr	F
182	Do	do	0		0				36	(a)	F
183	do	Geo. E. Dow	20		0				29	tr	F
184	do	do	10		tr				29	tr	F
185	Hancock County:										
186	East Orland	Tom Mason	87	13	1.0	6.5	4.1	6.2	1.6	3.7	F
187	Hancock County:	Public well	30							tr	F
188	do	Bored	22		0.5				33	20	F
189	do	Open	20								
190	do	Driven									
191	do	do	36	6	14	0.7	3.3	0.9	(b)	1.8	R
192	do	do	58	6.6	14	2.2	3.3	0.9	(c)	1.8	R
193	do	do	37	6.2	14	1.5	3.3	0.9	(d)	1.8	R
194	do	do									
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Analyses of spring waters in southern Maine.
[Parts per million.]

No.	Locality.	Owner.	Name of spring.	Total solids.	Organic and volatile matter.	Silica (SiO ₂).	Iron and aluminum oxides (Fe ₂ O ₃ +Al ₂ O ₃).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Bicarbonate radicle (HCO ₃).	Sulphate radicle (SO ₄).	Chlorine (Cl).	Carbonate radicle (CO ₃).	Total hardness as CaCO ₃ .	Analyst.
Androscoggin County.																		
203	Auburn.	Samoa Carbonating Co.	Auburn Diamond.	79		12	3.4	6.6	14	3.6			2.7	8.3	5.3	23		R. C. Stanley.
203a	Do.		Crystal Mineral.	74			3.1	7.7										L. G. Jordan.
204	Do.	Pejepscot Spring Water Co.	Pejepscot.	86	3.1	19	1.1	14	2.6		3.8	1.6		11	2.2	27		Stillwell and Glad- ding.
205	Durham.		Sylvan.	29		5.1	2.2	1.5	1.4		3.8	1.1		4.1	6.0	4.0		E. G. Jordan.
206	East Poland.	S. M. Pratt.	Keystone Mineral.	51	tr.	12	(c)	6.7	3.2		5.3			2.9	2.6	15		R. C. Stanley.
206a	Do.	do.	do.	104		5.6	(f)	2.2	15	3.1	4.2	0.8	60	3.4	5.0			W. W. Skinner.
206b	Greene.	A. B. Parker & Sons.	Glenrock Mineral.	67		5.6		2.2	12	1.8	5.1	3.2		4.0	5.2	26		W. W. Skinner.
207	East Turner.		Cliff.	30		6.6	1.9	2.6	1.3		2.4			6.2	3.9	7.6		L. G. Jordan.
208	Lewiston.	Windsor Mineral Spring Co.	Windsor Mineral.	154		18	0.7	42	1.9		5.8			29	5.1			Do.
208a	South Auburn.		American Chaly- beate.	174	38	11		8.3	27	5.5	2.2	6.3		11	3.5	61		S. P. Sharples.
209	Lewiston.	Highland Mineral Spring Water Co.	Highland Mineral.	84		11			15	2.6	3.1	8.0		10	5	29		F. L. Bartlett. C. F. Chandler. Do.
210	Do.	do.	do.	82		13			6.0		15			3.6	10	33		R. C. Stanley.
210a	Do.	do.	do.	52		11		5.9	0.9		2.8	1.2	23	4.6	2.7			W. W. Skinner.
211	North Auburn.		Auburn.	65		16	0.2	tr.	1.8		1.3		2.1	1.8	2.7			S. D. Hayes.
211a	South Poland.		Fountain Head.	68		19		5.9	tr.		10	0.8	18	1.1	1.6			F. L. Bartlett.
212	Do.	Hiram Ricker & Sons.	Poland.	63	4.0	19		8.3	2.7		2.7	1.2		1.4	2.7	21		C. F. Chandler.
213	Do.	do.	do.	24		24	0.4		2.7		2.9	1.2		1.6	2.7	21		U. S. Dept. Agri- culture.
214	Do.	do.	do.	109		15			14	2.4	0.3	0.9	56	3.3	5.9			W. W. Skinner.
214a	Do.	do.	Star.	242	38	9.9	(f)		16	4.0	33	0.7		8.3	50	54		F. L. Bartlett.
Cumberland County.																		
215	Bolsters Mills.	Alfred C. Clark.	Paradise.	0			0	0					23	0	2.3			F.
216	Do.		do.	17		0.6		0.05	0.8	0.3	2.7	0.3	5	7.1	0.6	4.9		Henry Carmichael.
217	Do.		do.	18	0.3	6.6		0.09	0.7	0.3	0.3			1.0	1.6	4.2		F. C. Robinson.
218	Do.		do.	30	0	8.6			3.2	0.7	5.9	0.9		1.1	9.1	6.8		F. L. Bartlett.
219	Falmouth Foreside.	Underwood Spring Corporation.	Underwood.	30		8.6			0.7		5.9	0.9		1.1	9.1	6.8		F. L. Bartlett.

	Harrison.	New Gloucester.	Fernal Spring Hotel Co.	Summit.	4.1	17	tr.	tr.	0.3	6.8	1.2	11	7.4	1.9	27	Do.
220					20	0.2	7.0			2.2	0.1	2.0	8.2	1.6	5.0	F. C. Robinson.
221	North Raymond.	Raymond Spring Co.	Raymond.		34	tr.	7.2		0.03	0.8	1.1	1.6	0.8	2.4	13	W. F. Haines.
222	Seco.		Cascade		30	22								3.0		State board of health.
223													(1)	14		F. Ohler.
224	Seabrook.	G. W. Soule				2.2			0	tr.				0.5	1.7	
225	South Freeport.															
226	Franklin County:															
227	Carrabassett.	Carrabassett Mineral Spring Co.	Carrabassett.				12		0.42	5.7	1.7	1.0	4.1	1.7	11	S. P. Sharples.
228	Do.	do.	do.		72		14	5.3	3.7	8.2	4.3	2.8	1.6	4.4	15	Salvatore La Bua.
229	Do.	do.	do.		28		14	1.0	5.7	2.5	1.3	1.4	1.0	3.7	3.6	Do.
230	Do.	do.	do.		38		12	0.6		6.0	1.6	1.0	0.5	4.1	1.7	S. P. Sharples.
231	Farmington Falls.	Farmington Falls Aqueduct Co.							0					tr.		F.
232	Rangeley.	Rangeley Lakes Hotel Co.	Rangeley Mineral.		58	12	12	tr.		7.8	2.0	1.2	12	1.9	9.3	F. R. Stillman.
233	South Strong.	R. W. Knowlton.	Knowlton's Soda.		42		16	m	tr.	2.1	0.7	4.3	4.3	2.7	8.6	H. L. Rowker.
234	Hancock County:															
235	Bluehill.	Bluehill Mineral Spring Co.	Bluehill Mineral.		79		21	m	1.0	3.1	1.7	3.9	7.6	3.1	23	
236	Do.	do.	do.		(o)		21	m	1.0	3.2	1.8	1.0	7.6	6.7	3.6	W. P. Mason.
237	Eastbrook.	R. B. Lowrie.	Katahdos.		20		7.3	0.2		1.6	0.5	1.8	2.7			J. W. Baird.
238	Mount Desert.		Mount Desert.		64	20	9.4	tr.		10	1.6		1.6	10	32	Davenport & Williams.
239																
240	Stonington.								0				29	0	13	F.
241	Tremont.												22	1.4	2.4	H. Carmichael.
242	West Hancock.		Ishka.		16		6.4		0.1	1.2	0.5	1.4	tr.	95		
243	Kennebec County:															
244	Augusta.	C. O. Cony.							0				tr.	21		
245	Chelsea.	W. H. Austin.											tr.	59		
246	Do.						8.8			2.3	0.5	3.3	1.1	4.4	4.7	
	Clinton (Morrison Corner).	H. E. Kendall.			33											41.23

a F. field assay by F. G. Clapp, G. C. Mason, or B. L. Johnson.
 b At 120° C. include phosphate radiate, 0.85. Lithium, none; bromine, none; iodine, none.

c Silica and alumina, 15.

d Analysis probably incorrect.

e For full analysis see p. 99.

f At 210° C.

g For full analysis see p. 97.

h Also nitric acid radiate (NO₃), 5.88; nitrous acid radiate (NO₂), 0.0032; PO₄, trace; metamorphic acid radiate (AsO₄), 0; Br, 0; iodine, 0; Mn, 0; L, 0.

i minute traces, 0.8.

j For full analysis see p. 101.

k Include aluminum (Al), 0.02; phosphate radiate (PO₄), 0.04; borate radiate (BO₃), 0.10.

l At 220° C.

m SO₄ less than 35 parts per million.

n Al.

* Include nitrate radiate (NO₃), 0.58; manganese (Mn), 0.25.

o Include nitrate radiate (NO₃), 0.66; manganese (Mn), 0.22.

Analyses of spring waters in southern Maine—Continued.

No.	Locality.	Owner.	Name of spring.	Total solids.	Organic and volatile matter.	Silica (SiO ₂).	Iron and aluminum oxides (Fe ₂ O ₃ +Al ₂ O ₃).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Bicarbonate radicle (HCO ₃).	Sulphate radicle (SO ₄).	Chlorine (Cl).	Carbonate radicle (CO ₃).	Total hardness as CaCO ₃ .	Analyst.
247	Kennebec County— Litchfield.....	Forest Springs Water Co.	Forest No. 1.....	2100	3.0	14	.....	tr.	22	1.6	5.3	2.7	.....	9.0	3.0	38	.....	.....
248	Do.....	do.	Forest No. 2.....	2555	3.3	14	.....	.....	8.8	1.5	3.8	0.8	.....	.....	.....	18	.....	.....
249	Do.....	do.	Forest No. 3.....	228	3.0	9.5	.....	.....	2.1	0.5	2.7	0.6	.....	1.1	2.2	6.1	.....	.....
250	Togus.....	do.	Hallowell.....	6.3	15	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
251	Vienna.....	do.	Vienna Sparkling.....	51	0	8.2	0.9	.....	13	1.5	0.1	1.9	.....	2.4	0.2	23	.....	C. F. Chandler.
252	Do.....	do.	do.....	43	0	15	tr.	.....	4.4	1.0	5.3	0.4	.....	0.6	0.1	16	.....	S. D. Hayes.
253	Winslow.....	do.	Ticonic Mineral.....	185	11	11	tr.	5.8	42	9.9	19	5.0	43	2.2	5.6	70	.....	S. K. Hitchings.
254	Do.....	do.	do.....	234	28	15	8.9	0	20	22	20	4.7	.....	29	6.1	.....	.....	F. C. Robinson.
255	Knox County: Rock- land in bottom of limestone quarry. Lincoln County: East Boothbay.....	do.	do.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
256	Do.....	do.	Boothbay Medical- nal.....	212	.....	11	ctr.	20	14	2.9	13	15	89	28	19	.....	.....	F. L. Bartlett.
257	Jefferson.....	do.	do.....	86	.....	16	.....	0.3	14	3.4	5.0	3.6	.....	7.1	5.5	31	.....	F. C. Robinson.
258	Nobleboro.....	do.	Samoset Mineral.....	425	tr.	12	19	.....	23	1.9	13	.....	.....	37	11	192	.....	H. C. Carmichael.
259	Oxford County: Hartford.....	Consolidated General Mineral Water Co. do.	Mount Hartford Mineral.....	436	.....	.....	8.5	0.1	3.2	0.7	4.2	0.6	.....	4.0	1.1	9.6	.....	J. W. Mallett.
259a	Do.....	do.	do.....	46	.....	9.0	.....	.....	4.4	1.0	4.0	0.8	.....	20	1.6	4.0	.....	W. W. Skinner. ^a
260	Milton plantation. Do.....	Mount Zircon Spring Co.	Mount Zircon.....	33	2.2	9.7	ctr.	0.7	2.3	.....	1.0	9.8	.....	5.4	1.5	.....	.....	F. L. Bartlett.
261	Paris.....	Paris Hill Water Co. do.	Crocker Hill (pub- lic supply)/No. 1.....	211	3.7	1.2	0.3	.....	0.5	tr.	1.8	.....	.....	.....	3.9	.....	.....	.....
261	Do.....	do.	Crocker Hill (pub- lic supply)/No. 2.....	213	2.1	1.7	0.4	.....	0.5	0.1	2.3	.....	.....	.....	3.6	.....	.....	.....
261	Do.....	do.	Crocker Hill (pub- lic supply)/No. 3.....	214	2.7	1.8	0.5	.....	0.6	0.2	2.5	.....	.....	.....	3.9	.....	.....	.....
262	Do.....	do.	Mount Mica Min- eral.....	.....	.....	.....	0	.....	0	.....	.....	.....	10	.....	2.2	.....	.....	F
263	Rumford Falls.....	Rumford Falls Power Co.	Cataract.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	22	tr.	4.9	.....	.....	F
264	Sumner.....	United Mineral Springs Co.	Mount Oxford.....	3.4	.....	8.0	.....	2.1	6.6	0.3	1.5	.....	.....	1.4	2.6	11	.....	E. E. Calder.

[illegible]

a Include lithium (Li), trace.

^b SO₄ less than 35 parts per million.

CAL.

and Inclu

* For full analysis see p. 181.

Nos. 1 and 2 from reservoir,

For full analysis see p. 195.

h With Al_2O_3 .

For full analysis see p. 203.

For full analysis, see p. 207.

k Temporary, 25.9; permanent, 16.

Includes CaCl_2 .

m Include lithium

* Include Br, trace.

o For full analysis see p. 201.

Total solids.—The total solids constitute the residue left on evaporation of a water sample. Those reported in southern Maine well and spring waters range from 13 parts per million in a spring at Naples to 4,055 parts in a well at North Haven. The high percentage of mineral matter in the North Haven water and in several other wells near the sea which show abnormally high solids is generally due to an admixture of ocean water that penetrates inward along joint cracks in the rocks. With one exception, the highest amounts of total solids in southern Maine which are believed to be due to the natural composition of the water are somewhat under 500 parts per million and are found in several widely scattered wells drilled in slate in Penobscot and Somerset counties. The minimum of total solids in slate is 52 in a well at Portland. The figures in Aroostook County slates (and "slated limestones") in northern Maine are higher, ranging between 200 and 800 parts per million. A single well at Bangor reports 834 parts per million.

In granite one well at North Sullivan reports 364 parts per million, and one in Waldoboro 419 parts. These figures are high for granite, as the total solids in granite waters generally run below 200. Most springs issuing from sand and gravel give low figures, many running below 30. One spring, at South Freeport, reported only 2.8 parts per million of total solids, but this figure is probably wrong.

The reports of the State board of health contain many sanitary analyses which show the amount of total solids in spring waters, but as the springs are mostly private ones, and as the material from which they issue is not known, or known only through correspondence, the analyses would be of little value in this report, and only two or three are given.

Organic and volatile matter.—Organic and volatile materials are much greater in amount in the waters analyzed than might be expected in deep-well and spring waters. It should be noted, however, that some of the highest figures occur in analyses for which the name of the chemist is not known, and hence their accuracy is open to doubt. Normally, with a few exceptions, the organic and volatile matter ranges from 5 to 100 parts per million in wells, and from 0 to 30 parts in springs. An exceptionally large amount of "organic and volatile matter" may be due to pollution of the water, to water of crystallization, or to volatile mineral components..

Silica.—The amount of silica in Maine waters is always low. As shown by the diagrams, it ranges from 7 to 25 parts per million for well waters, exclusive of the wells where it can be attributed to sea water. In spring waters the silica runs from 0.24 part to 21 parts. The highest amount, 21 parts, occurs in the Blue Hill Mineral Spring.

Iron and aluminum oxides.—The figures for iron and aluminum oxides are much more constant than those for any other ion or group

of ions. With the exception of iron when reported alone, they are the lowest of all the materials commonly estimated. (See lowest line in Pls. IV, VI, and VIII.) In well waters from granite and similar rocks these minerals run from 1 to 8 parts per million; in those from sand and gravel, 1 to 2 parts; in spring waters, 0.2 to 9 parts. The highest amounts occur in spring water from a limestone quarry at Rockland.

Iron.—Most of the analyses reporting iron separately from aluminum are field assays, and in them iron is generally found to be absent. Most Maine waters are destitute of iron in appreciable quantities. As half a part per million of this mineral is recognizable to the taste, it will be seen that much iron would make the waters unusable. The greatest amount reported, 5 to 10 parts per million, is in the wells of the Northern Maine Seaport Railroad Company in Waldo County. This amount of iron in a water would make it undrinkable; hence it is probable that the figures given for iron in these wells may include alumina.

A number of mineral springs also report high iron, and to some of these the statement just made may possibly apply. As a rule, the amount of iron in springs of this State runs below 1 part per million. The Blue Hill Mineral Spring, which is said to issue from a rock containing a large quantity of iron, contains only 3.2 parts per million of this mineral.

Calcium.—Calcium, a constituent of lime, is one of the most abundant ingredients. It is generally highest in limestone, and runs from 40 to 160 parts in the areas of calcareous slates. Exceptional figures are much higher. The lowest known figure for calcium in slate water is 4. In granite it ranges from 1 part per million in a well on Greenings Island to 62 parts in a North Sullivan well. In gravel waters the amount is from 3 to 6 parts. In springs it ranges from a mere trace to 42 parts.

Magnesium.—In waters where calcium occurs magnesium also is found, but generally in much smaller quantities. In granite waters it ranges from 2 to 10 parts per million, in slate from 1 to 30, and in sand and gravel from 1 to 5. In calcareous slates in northern Maine the amount of magnesium runs from 15 to 40 parts. In spring waters the amount of this element is very uncertain, running as high as 14 parts, but being in most springs below 3. The analysis of limestone water from Rockland shows 22 parts of magnesium, nearly as many as of calcium—29. In two analyses, those of the Highland Mineral Spring at Lewiston and the Keystone Mineral Spring at Auburn, magnesium without calcium is reported. This is evidently a mistake, and it is possible that part of the solid matter reported as magnesium is in reality calcium.

Sodium.—Sodium is one of the constituents of common salt and of sea water, which explains why it is so high in certain analyses. Normally it runs from 7 to 60 parts per million in granite, from 3 to 30 parts in slate, and from 1 to 10 parts in gravel. In spring waters it is variable, but seldom exceeds 20 parts. In most Maine waters sodium is much lower than calcium, as shown by the diagrams. In sea water, however, sodium far exceeds calcium and magnesium in amount. The fact that in analysis No. 155 calcium is much in excess of sodium indicates that perhaps the high total solids may not be due entirely to sea water, as would appear at first inspection of the diagram.

Potassium.—Smaller quantities of potassium than of sodium are found in most waters. The element is usually in equilibrium with chlorine, as is sodium, and it is also found in sea water. In granite the amount ranges from 0.5 to 13 parts per million, in slate from 0.8 to 17, and in sand and gravel it is below 3. In two well waters the amount of potassium is reported greater than that of sodium. In spring waters it runs from 0.2 to 15 parts.

Bicarbonate radicle.—All carbonates occurring in Maine well and spring waters are believed to exist in the bicarbonate or acid-carbonate form, as several hundred tests for the normal or alkaline carbonate resulted negatively. The figures in the bicarbonate radicle column are mostly the results of field assays made according to the standard method of the United States Geological Survey,^a and are approximate only. The tests made show the amount of bicarbonates to range from 9 to 143 parts per million in granite, 20 to more than 500 in slate, 40 to 167 in clay, 16 to 80 in bowlder clay, and 10 to 128 in sand and gravel. One report from a well in slate gives 765 parts per million. The higher figures, while somewhat scattering in distribution, are mostly from the northeastern quarter of the State. In Aroostook County none of them are under 100 and many exceed 300 parts per million. In spring waters the bicarbonate radicle is generally low, one refined analysis showing only 0.14 part. In a few springs the bicarbonates exceed 100 parts per million.

Carbonate radicle.—Most of the analyses of spring waters and a few analyses of well waters made by chemists not connected with the United States Geological Survey report calcium, sodium, and other carbonates. There is no way of determining from these analyses what proportion of the carbonates exist in the form of the normal carbonate radicle and what proportion in the bicarbonate form. In recomputing the results, therefore, it has been necessary to express them simply as "carbonate radicle" (CO_3), though these are probably all bicarbonates (HCO_3). Although normal carbonates are not known

^a Leighton, M. O., Field assay of water: Water-Supply Paper U. S. Geol. Survey No. 151, 1905, pp. 66-69.

to have been found in Maine waters, they can not be said with certainty to be absent.

Sulphate radicle.—All sulphates occurring in Maine waters have been recomputed to the sulphate radicle (SO_4). Small amounts of this compound occur in most waters, and in some they are high. In granite they range from a mere trace to 36 parts per million, in clay from 0 to 53 parts, and in gravel and sand from 0 to 11 parts. In spring waters the sulphates range from 0 to 37 parts, but are generally below 10.

Chlorine.—Chlorine, a constituent of common salt, is one of the most variable components of natural waters. It ranges in the Maine waters analyzed from less than 1 part per million to as high as 1,790 parts in one well which was invaded by sea water. The highest chlorine that is believed to be due to the composition of the rock is somewhat under 200 parts. In some portions of the country (as in places in New York State), where the rocks contain salt, however, the waters are high in chlorine. Normal chlorine lines and the limitations of their use are explained on pages 27–28. In the majority of well waters the chlorine is above the normal as given for the local surface waters. In most deep wells which are properly cased this is due to chlorine dissolved from the rocks and in open wells to the entrance of surface waters.

Hardness.—The hardness of waters may be classed as temporary, due to the carbonates and bicarbonates of calcium and magnesium; or permanent, due to sulphates, chlorides, or nitrates of the alkali earths. A large part of the hardness in Maine waters is temporary and can generally be removed by boiling, which precipitates the hardening constituents. Aside from the analyses made by the state board of health, few tests for hardness have been made. In general the waters outside of Aroostook County and parts of Penobscot and Somerset counties are soft; and when they are described by residents or in the table at the end of the report as “hard” the term is used only relatively, with reference to softer waters in the same region. The total hardness of waters in southern Maine ranges up to 300 parts per million, the highest figures being shown in Penobscot County, where the rocks are slightly calcareous. The hardness of spring waters, however, seldom exceeds 20 parts. The reports of the state board of health include several hundred analyses of spring waters which give the hardness. Few of these are published here, as the material from which the spring issues is known only through correspondence.

Lithium.—Few tests for lithium in Maine waters have been made. One or two well waters which issue from granite report traces of this element, and amounts up to 0.01 part per million are reported to have been found in spring waters issuing from granite and gneiss.

Other substances.—In a few analyses tests have been made for other elements. Manganese, strontium, rubidium, phosphates, arsenates, and borates have been found as mere traces. Tests for bromine and iodine have resulted negatively. None of the substances mentioned have been found in quantities large enough to give the water medicinal properties. The most complete analyses, showing something in respect to the probability of finding the rarer elements in spring waters, are those made by the Bureau of Chemistry, United States Department of Agriculture.

DESCRIPTION OF UNDERGROUND WATERS BY COUNTIES.

ANDROSCOGGIN COUNTY.

GENERAL DESCRIPTION.

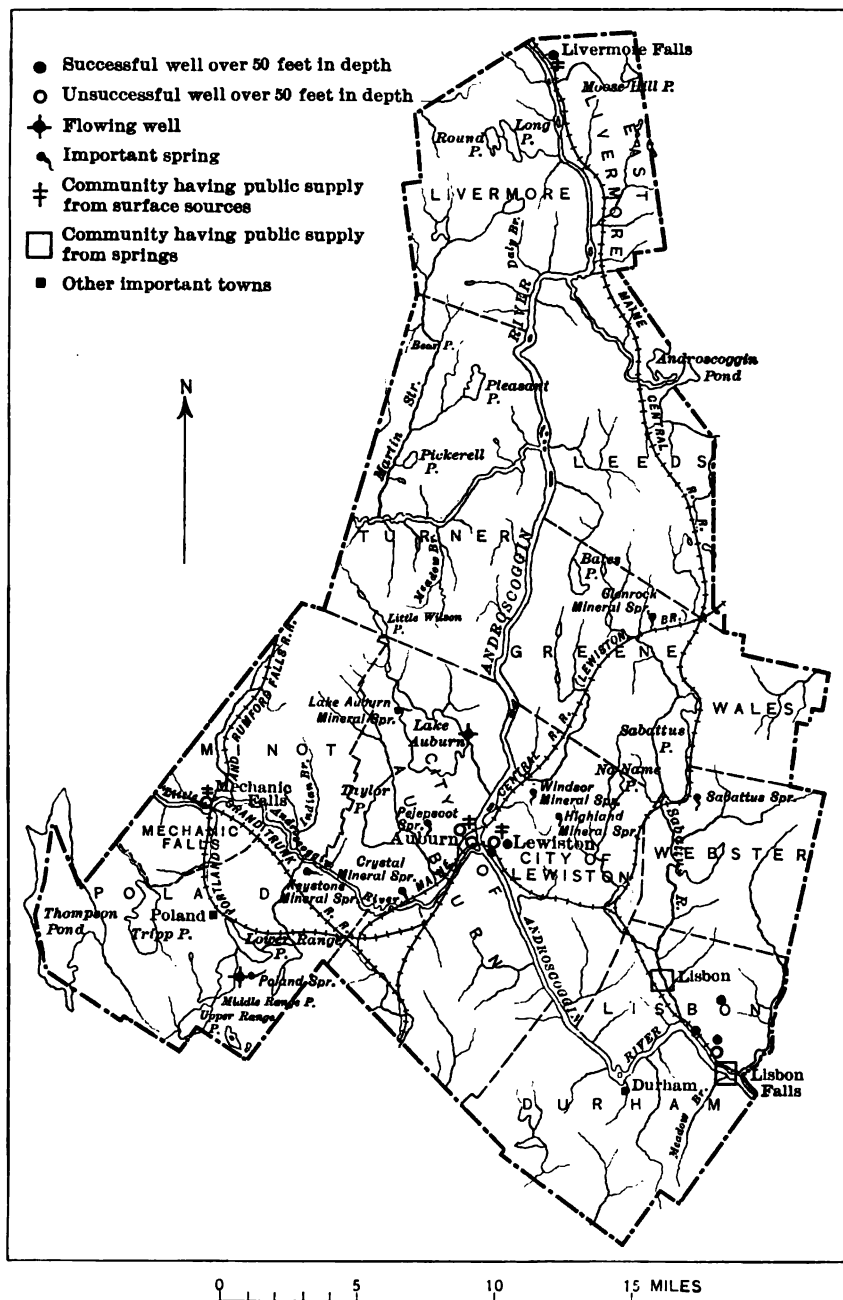
Androscoggin County is situated in the southwestern part of Maine, on both sides of Androscoggin River. It is one of the smallest counties in Maine, having a length of 40 miles, an extreme breadth of 25 miles, and a total area of only 480 square miles. The population, according to the census of 1900, was 54,242. Lewiston is the largest city, having a population of 24,997. Auburn, the county seat, on the opposite side of the river from Lewiston, contained 13,971 inhabitants. This county is moderately hilly, ranging in altitude from 100 to more than 800 feet.

UNDERGROUND WATERS.

RELATION TO ROCKS AND SURFACE DEPOSITS.

Distribution of rock types.—The rocks of Androscoggin County consist for the most part of complex intrusions of granite and gneiss in schist, but a strip along the eastern border of the county, north of Lisbon, is underlain by slate. In the vicinity of Lewiston and Auburn the rocks consist mostly of hard gneissic schist or granitic gneiss, cut by small granite dikes. In most places within this strip the rock is distinctly bedded, but the strike and dip are extremely variable, the strata being much contorted in places. In some localities the joints are open and the rock is decomposed, allowing penetration of water downward; in other places the rock is dense, and all the cracks are tightly closed. This probably accounts for the failure of several deep wells at Auburn and Lewiston. Farther away from the boundary of the slate area, and in some places near its border the rock is true granite. A map of Androscoggin County showing the distribution of deep wells, important springs, and communities having public water supplies forms Pl. XI.

Surface deposits.—The greater part of the uplands of the county is covered by boulder clay and irregular gravel deposits, locally of



MAP OF ANDROSCOGGIN COUNTY.

Showing distribution of deep wells, important springs, and communities having public supplies.

considerable thickness. Along the rivers, however, rather extensive lowlands consist of clay rising to a maximum elevation of about 200 feet. At Lewiston a number of brickyards make use of this clay. At Lewiston Upper Station the clay is 20 feet thick and in places is overlain conformably by stratified sand and underlain by coarse gravel. In other parts of Lewiston the clay is more than 30 feet in thickness. Gravel underlies the clay in the vicinity of Lisbon Falls and Lewiston, and probably nearly everywhere in the Androscoggin Valley. Many flat sand and gravel deposits extend along the valley of Little Androscoggin and other rivers and surround the principal lakes and ponds. The total thickness of these deposits varies greatly, but in extreme cases along the valleys it is as much as 60 feet. On the highlands the drift is thinner, generally not more than 5 to 15 feet thick.

WELLS.

GENERAL DESCRIPTION.

Types of wells.—The majority of the wells of Androscoggin County are open surface wells, but some driven wells are used, and in Lewiston, Auburn, and Lisbon Falls there are a few drilled wells. The open and driven wells vary in depth from 10 to 35 feet, and in the valleys they are generally successful, so far as the quantity of water is concerned, although some have been dug to rock without success, and the water in many of them becomes very low or gives out in a dry season. In general dug wells are the only type of shallow wells which can be used on the hills, but driven wells are more satisfactory in the sands and clays of the valleys.

Drilled wells.—In parts of the county where it is not possible to obtain water of suitable quality or in sufficient quantity from surface wells drilling should be adopted. Little drilling has been done as yet, but the method will be used more and more in future. Some hesitation may be felt in regard to it at Lewiston and Auburn because several of the wells, including one 654-foot well, have been failures. It is possible that in this vicinity open joint cracks containing water are so rare and superficial that successful wells can not be obtained; but the region has hardly been fairly tested, and it is possible that in some parts of these cities there may be plenty of water in the rocks. If tests are made, it will probably not pay to drill below 300 feet. Most of the wells already sunk have been 6-inch wells, but one 8-inch well was drilled. The depths range from 50 to 654 feet.

Quality of water.—Little can be said in regard to the quality of water in Androscoggin County, as few analyses have been made. Field assays of the water from dug wells at Auburn and one at Mechanic Falls show a very low mineral content. A drilled well in

granite at South Poland gave 98 parts per million of total solids. A well in Auburn, location not known, reports 112 parts per million of total solids. Throughout the county the water is soft, but in drilled wells it is less so than in the surface wells. In nine springs, the waters of which have been analyzed, the total solids range between 29 and 154 parts per million. In one driven well and one drilled well the water is said to overflow the surface.

Uses.—In all parts of the county the chief use of well water is for domestic and farm purposes, and it is seldom used for anything else. At Lewiston, however, water from gravel is used in Bates's mill for bleaching purposes.

DETAILED DESCRIPTION.

Lewiston and Auburn.—At Lewiston and Auburn wells drilled in the solid rock have generally been failures. A well of the Standard Dry Plate Company, corner of Bates and Pine streets, Lewiston, found very little water. A well belonging to Mr. John Picket, now deceased, on Highland street, Auburn, got water, but is now abandoned. One of the most conspicuous failures in Maine is a well belonging to the Turner Center Creamery in Auburn. This well was drilled by an experienced driller to a depth of 654 feet, but absolutely no water was found below 8 feet from the surface. The first 90 feet was through gravel and clay, the rest in gneiss. The quality of water, where found, is generally good. Analyses of well waters in Auburn are given in the table on pages 82, 83 (Nos. 175 and 196).

The plant at Bates's mill, Lewiston, consists of 15 driven wells ranging in depth from 30 to 40 feet. The formation at the mill consists of 20 feet of gravel ("made ground") resting on about 5 feet of clay, below which lies 2 feet of gravel containing a plentiful supply of water. The gravel bed slopes to the south and appears at the bottom of all these wells and also at the bottom of a 65-foot well owned by the same company, situated 200 feet beyond the last well of the system. The water tastes strongly of iron. It is used in bleaching, and the pumps are run fifteen hours a day, pumping an average volume of 350 gallons a minute.

Dug wells are far more common than driven wells in this vicinity, and, except in the clay areas, are generally of moderate depth and are fairly satisfactory if protected from pollution. In the clay areas wells should be driven or drilled through the clay into the underlying sand and gravels, which generally contain plenty of water. Some open wells are blasted in rock, the chief value of this method being to furnish a reservoir for the water of the overlying drift. At North Auburn there are a few dug wells 40 to 60 feet in depth, most of them many years old. Several drilled wells are reported within the town

limits. A few dug wells and springs are pumped by windmills. In the southern part of the town there are considerable areas of sand plain in which water can be easily obtained at shallow depths. Dug wells have been used mostly thus far, but some persons are now using driven wells. Several commercial mineral springs are situated in these towns and will be described under the appropriate heading. (See pp. 96-99, 103.) The public supply of Auburn and Lewiston is taken from Lake Auburn. This would be excellent water if properly protected, but unless the building of cottages and pleasure resorts on the lake shores is regulated and boating is stopped the supply will soon become dangerous for drinking.

Poland.—The conditions in the town of Poland vary greatly. Considerable areas in the eastern part of the town and in the vicinity of the ponds consist of sand and clay plains, but a large part of the town is hilly. Open wells are the rule, being generally dug to bed rock, and some of them are blasted into the rock itself as much as 4 to 10 feet. Only one drilled well is known. This is situated 700 yards from Poland Spring and was drilled in granite in the hope of tapping the spring supply. Needless to say, the attempt failed. The analysis of water from this well is given in the table (No. 2).

Mechanic Falls.—A number of years ago test wells were sunk at Mechanic Falls to depths of 30 to 60 feet through clay and fine sand, in order to get a public supply. A little water overflowed the surface, but the amount was too small, so the wells were abandoned. As the village lies on broad clay and sand plains bordering Little Androscoggin River, the water is here abundant and is easily obtained by dug and driven wells. The water is obtained on top of the clay, but if this is penetrated a more abundant supply of better quality will be found. It is possible, even, that flowing wells may be obtained in places. Driven wells are recommended in preference to dug wells wherever practicable, but all forms of wells should be sunk through the clay.

Lisbon.—Along the river at Lisbon water is found in shallow wells in sand resting on clay. Several wells drilled in granite at Lisbon Falls were sunk to depths ranging from 50 to 187 feet, and all but one were successful as regards quality of water. Only one field assay (No. 1 of the table) is available to show the mineral content of the water here.

East Livermore.—At Livermore Falls one or more shallow drilled wells have been sunk, but no information is at hand regarding them.

Other towns.—In the towns of Danville, Minor, Webster, Wales, Greene, Turner, Leeds, and Livermore no wells are known to have been drilled, the type generally in use being the ordinary open wells used at most farmhouses.

SPRINGS.

General statement.—Commercial mineral springs are more abundant in this county than in any other county of Maine, no fewer than seven springs reporting sales of water being situated within its borders. These are as follows:

Crystal Mineral Spring, Auburn.
Highland Mineral Spring, Lewiston.
Keystone Mineral Spring, East Poland.
Pejepscot Spring, Auburn.
Poland Spring, South Poland.
Sabattus Springs, Sabattus.
Windsor Mineral Spring, Lewiston.

In addition to these there are several other springs of interest, the water of which is not sold.

Crystal Mineral Spring.—The Crystal Mineral Spring is owned by the Samoar Carbonating Company, of Lewiston. It is situated on a sloping hillside 3 miles southwest of Auburn depot, and the water issues from undulating deposits of stratified sand, known as kames, which rest on a bed of clay. The water is collected in a cement-lined and glass-covered masonry tank, about 8 feet square and 4 feet deep, inclosed in a spring house where the water was formerly bottled. It is now hauled to Lewiston and bottled there, being mostly carbonated for soda water and ginger ale, and sold under the trade name Samoar water. The temperature of this water at the spring is 47° and the measured overflow is 6 gallons a minute. The water has no color, odor, or taste, and on account of its situation distant from houses there is no chance for pollution. The analysis, recomputed from that given in the circular issued by the owner, is given in the table (No. 203a).

Glenrock Mineral Spring.—The Glenrock Mineral Spring is situated in the town of Greene, $2\frac{1}{2}$ miles south of the post-office. It is owned by A. B. Parker & Sons, of Greene. The water issues from gravel deposits on a gentle slope in an open field. The spring is incased in granite curbing cemented to an impervious stratum, and is reported to flow 18 gallons a minute, not varying according to season. The temperature is $47\frac{1}{2}^{\circ}$. The water is colorless, odorless, and tasteless, and is of excellent quality. It is used as a table and medicinal water by many families in Lewiston and Auburn. The analysis of the water is given in the table (No. 206b), the composition being taken from the circular issued by the owners and recomputed according to the standard method.

Highland Mineral Spring.—The Highland Mineral Spring is situated on a southward-sloping hillside in the city of Lewiston, about 3 miles northeast of the post-office. It is owned by the Highland Spring Water Company, of New York. The hill on which the spring is

situated is composed of gneiss and schist cut by pegmatite dikes, and a covering of 1 to 5 feet of boulder clay overlies the rock. The water occurs in a vertical 6-inch crack parallel with the stratification of the gneiss, entering from the direction of the summit of the hill on the north side of the spring. The water is believed to be derived from the rain and snow falling on the hillside within a few hundred feet of the spring, being held in the drift and the upper crevices of the rock until it emerges at the spring. The spring is reported to flow 20 gallons a minute in a wet season, but diminishes somewhat during the summer. The temperature averages 42° , varying a little during the year.

The spring is inclosed with a granite curbing, and the whole is covered with a small spring house. The bottling house is 50 feet away. The situation is almost ideal for a mineral spring, as the hill rises 100 feet or so above it and is covered mostly by thick woods. There are no houses on the hill except two cottages on the summit, several hundred yards from the spring, separated from it by a small ravine. These are occupied for a month in summer by the treasurer of the company—a prominent New York physician—and as every precaution is taken in respect to drainage, there is practically no danger of the spring water becoming polluted. The water is bottled near by and shipped to New York and other cities. Valuable medicinal properties are claimed for it by the owners. The water retails in New York for \$2 a 5-gallon carboy, or the same rate for a case of 12 quarts. This is colorless, odorless, and tasteless.

Several analyses have been made of this water (Nos. 209, 210, and 210a of the table), but the most complete is that made by W. W. Skinner, of the Bureau of Chemistry, United States Department of Agriculture, in connection with cooperative work on mineral waters conducted by the Geological Survey and the Bureau of Chemistry. The proportions of the various constituents are as follows:

Analysis of water from Highland Mineral Spring.

[W. W. Skinner, analyst.]

Gases (cubic centimeters per 1,000 grams at 0° C. and 760 mm. pressure):

Carbon dioxide (CO_2), free.....	38.2
Carbon dioxide (CO_2), set free from bicarbonates on evaporating to dryness.....	4.2
	Parts per million.
Phosphoric acid radicle (PO_4).....	None.
Metaboric acid radicle (BO_2).....	None.
Arsenic acid radicle (AsO_4).....	None.
Silica (SiO_2).....	11.40
Sulphuric acid radicle (SO_4).....	4.65
Bicarbonic acid radicle (HCO_3).....	22.90
Nitric acid radicle (NO_3).....	None.

	Parts per million.
Nitrous acid radicle (NO_2).....	None.
Chlorine (Cl).....	2.20
Bromine (Br).....	None.
Iodine (I).....	None.
Iron and aluminum (Fe and Al).....	.35
Manganese (Mn).....	None.
Calcium (Ca).....	5.86
Magnesium (Mg).....	.94
Potassium (K).....	1.21
Sodium (Na).....	2.79
Lithium (Li).....	None.
Ammonium (NH_4).....	.021
Oxygen to form Fe_2O_3 and Al_2O_3	52.321
Free ammonia.....	.02
Albuminoid ammonia.....	.05
Nitrogen as nitrates.....	Traces.
Nitrogen as nitrites.....	None.
Oxygen consumed.....	1.50

Keystone Mineral Spring.—The Keystone Mineral Spring is owned by E. H. Pratt, of East Poland. The spring is situated on a gently sloping hillside in the eastern part of the town of Poland, about a mile north of Empire Road station on the Grand Trunk Railway. The water issues from a nearly horizontal seam 4 feet or so from the surface, overlain by a bed of granite and underlain by gneiss. The beds of the gneiss strike N. 30° to 40° W. and dip 35° NE. The hill rises 10 feet higher within 100 feet southwest of the spring and 25 feet higher 200 feet north of the spring. To the east is a little valley; to the southwest lies an undulating sand plain a quarter of a mile in extent. The water apparently comes from the southwest, where it is caught on this sand plain, sinks into the underlying rock, and finds its way along the contact plane between the granite and the gneiss.

This spring is walled with a granite curb and inclosed in a bottling house, and is well protected from pollution. The temperature in the basin is 50° , the water being probably warmed somewhat by contact with the air. There is no color or odor and little, if any, taste. The measured overflow is a trifle over 3 gallons a minute and is reported to fluctuate very little with the weather or the season. The water has been analyzed, and the composition reported by the owners and recalculated into ions and parts per million according to the standard rules is given in the table (No. 206).

The best analysis of this water is one made by W. W. Skinner, of the Bureau of Chemistry, United States Department of Agriculture, in connection with cooperative work on mineral waters conducted by the Geological Survey and the Bureau of Chemistry. This analysis is as follows:

Analysis of water from Keystone Mineral Spring.

[W. W. Skinner, analyst.]

Gases (cubic centimeters per 1,000 grams at 0° C. and 760 mm. pressure:

Carbon dioxide (CO ₂), free.....	9.2
Carbon dioxide (CO ₂), set free from bicarbonates on evaporating to dryness.....	10.9
	Parts per million.
Phosphoric acid radicle (PO ₄).....	None.
Metaboric acid radicle (BO ₂).....	None.
Arsenic acid radicle (AsO ₄).....	None.
Silica (SiO ₂).....	11.60
Sulphuric acid radicle (SO ₄).....	3.43
Bicarbonic acid radicle (HCO ₃).....	59.53
Nitric acid radicle (NO ₃).....	.88
Nitrous acid radicle (NO ₂).....	None.
Chlorine (Cl).....	5.20
Bromine (Br).....	None.
Iodine (I).....	None.
Iron (Fe) and aluminum (Al).....	.39
Manganese (Mn).....	None.
Calcium (Ca).....	14.72
Magnesium (Mg).....	3.11
Potassium (K).....	.84
Sodium (Na.).....	4.23
Lithium (Li).....	None.
Ammonium (NH ₄).....	.....
Oxygen to form Fe ₂ O ₃ and Al ₂ O ₃.....	.....
	103.93
Free ammonia.....	None.
Albuminoid ammonia.....	None.
Nitrogen as nitrates.....	.20
Nitrogen as nitrites.....	None.
Oxygen consumed.....	6.50

Keystone Spring water is bottled and mostly peddled in Lewiston and Auburn, but some is shipped by rail. Examination of the spring shows it to be probably secure from danger of pollution.

Pejepscot Spring.—Pejepscot Spring is situated on Golf Hill in Auburn, about 1½ miles northwest of the post-office. The water is reported by the owners to issue from a bed of sand near the base of the hillside. It is colorless, tasteless, and odorless, and is reported to flow about half a gallon a minute. It is put on the market for medicinal and table use. The analysis given in the table (No. 204) is recomputed from that furnished by the owners.

Poland Spring.—Poland Spring is the best-known spring in Maine. It is owned by Hiram Ricker & Sons (Incorporated) and is situated on Ricker Hill at South Poland. This is a hill of considerable size, rising 300 feet above the surrounding valley and consisting almost

entirely of granite and granite gneiss, covered only by 1 to 30 feet of hardpan or boulder clay. On top of the hill stands the Poland Spring House, a famous summer resort.

On the north and east sides of the hill the formation is typical granite, but on the south and west slopes it is much more gneissic in character. The spring is situated on the east slope of the hill, 84 feet below the summit. In the immediate vicinity of the spring the rock is in few places more than 3 feet below the surface, and much of the surface is bare rock which slopes with the hill. The water issues from cracks in a dike of porphyry which is about 10 feet wide at the spring and strikes about N. 80° W., as nearly as can be estimated. This dike has been traced by the owners of the spring for a distance of 200 feet and its width diminishes at the southeast end to about 1 foot. Its other relations can not be determined without excavation, but it is reported to have slightly into the hill. The spring itself is covered by a glass case and protected from too close intrusion by a marble wall surmounted by an iron grating. By looking down through the glass cover a number of narrow cracks a small fraction of an inch in width can be seen running parallel with the sides of the dike. The surface of the dike is weathered rather whitish and is somewhat decomposed. It is from this part of the dike that the water emerges.

No pains or expense have been spared by the owners of the Poland Spring to collect every available gallon of the water which emerges, and to protect the spring from all possible pollution. A trench was once excavated along the dike for many feet, and the dike covered with cement, to prevent the exit of water anywhere except in the spring. The curbing has been carefully cemented to the rock to prevent all surface wash, and over the spring has been built an elaborate and expensive marble spring house. The hotel stands on the summit of the hill several hundred feet distant, and all drainage from the hotel and stables is carried in tightly jointed pipes down the opposite slopes.

Poland water has no color, odor, or taste, and is very low in mineral matter, as shown by the analyses given in the table (Nos. 212, 213, 214, and 214a). The first and second analyses are reported by the owners of the spring and the various constituents have been recalculated into the ionic form and parts per million, according to the standard method.

The best analyses of the Poland Spring water were made by W. W. Skinner, of the Bureau of Chemistry, United States Department of Agriculture, in connection with cooperative work on mineral waters conducted by the Geological Survey and the Bureau of Chemistry. One of these, made in 1905, has been published,^a but is repeated here.

^a Haywood, J. K., Mineral waters of the United States: Bull. No. 91, U. S. Dept. Agr., Bur. Chemistry 1905, pp. 32-33.

Analysis of Poland Spring water.

[W. W. Skinner, analyst.]

Gases (cubic centimeters per 1,000 grams at 0° C. and 760 mm. pressure):

Carbon dioxide (CO ₂), free.....	5.6
Carbon dioxide (CO ₂), set free from bicarbonates on evaporating to dryness.....	8.8
	Parts per million.
Silica (SiO ₂).....	24.1
Sulphuric acid radicle (SO ₄)	3.6
Bicarbonic acid radicle (HCO ₃).....	48.4
Carbonic acid radicle (CO ₃).....	.....
Nitric acid radicle (NO ₃).....	5.89
Nitrous acid radicle (NO ₂).....	.0032
Phosphoric acid radicle (PO ₄).....	Trace.
Metaboric acid radicle (BO ₂).....	None.
Arsenic acid radicle (AsO ₄).....	None.
Chlorine (Cl).....	5.0
Bromine (Br).....	None.
Iodine (I).....	None.
Iron (Fe) and aluminum (Al).....	.4
Manganese (Mn).....	None.
Calcium (Ca).....	13.9
Magnesium (Mg).....	2.1
Potassium (K).....	2.4
Sodium (Na).....	6.9
Lithium (Li).....	Minute trace.
Ammonium (NH ₄).....	.008
Oxygen to form SiO ₂ and Fe ₂ O ₃	1.2
	133.9012
Free ammonia.....	.008
Albuminoid ammonia.....	.051
Nitrogen as nitrates.....	1.33
Nitrogen as nitrites.....	.001
Oxygen required.....	.45

HYPOTHETICAL FORM OF COMBINATION.

	Parts per million.
Ammonium chloride (NH ₄ Cl).....	0.024
Lithium chloride (LiCl).....	Minute trace.
Potassium chloride (KCl).....	4.6
Sodium chloride (NaCl).....	4.6
Sodium sulphate (Na ₂ SO ₄).....	5.3
Calcium phosphate (Ca ₃ (PO ₄) ₂).....	Trace.
Sodium nitrate (NaNO ₃).....	8.07
Sodium nitrite (NaNO ₂).....	.0048
Sodium bicarbonate (Na(HCO ₃)).....	4.4
Magnesium bicarbonate (Mg(HCO ₃) ₂).....	12.6
Calcium bicarbonate (Ca(HCO ₃) ₂).....	46.1
Ferric oxide (Fe ₂ O ₃) and alumina (Al ₂ O ₃)	.6
Calcium silicate (CaSiO ₃).....	7.3
Silica (SiO ₂).....	20.3

113.8988

The second analysis by the Bureau of Chemistry was made at a later date and has not been previously published. The various constituents are as follows: *

Analysis of Poland Spring water.

[W. W. Skinner, analyst.]

Gases (cubic centimeters per 1,000 grams at 0° C. and 760 mm. pressure):

Carbon dioxide (CO ₂), free.....	2. 10
Carbon dioxide (CO ₂), set free from bicarbonates on evaporating to dryness.....	10. 20
	Parts per million.
Phosphoric acid radicle (PO ₄).....	Traces.
Metaboric acid radicle (BO ₂).....	None.
Arsenic acid radicle (AsO ₄).....	None.
Silica (SiO ₂).....	15. 40
Sulphuric acid radicle (SO ₄).....	3. 29
Bicarbonic acid radicle (HCO ₃).....	55. 63
Nitric acid radicle (NO ₃).....	3. 98
Nitrous acid radicle (NO ₂).....	None.
Chlorine (Cl).....	5. 90
Bromine (Br).....	None.
Iodine (I).....	None.
Iron (Fe) and aluminum (Al).....	. 32
Manganese (Mn).....	None.
Calcium (Ca).....	14. 37
Magnesium (Mg).....	2. 38
Potassium (K).....	. 90
Sodium (Na).....	6. 34
Lithium (Li).....	None.
Ammonium (NH ₄).....	. 011
Oxygen to form Fe ₂ O ₃ and Al ₂ O ₃	. 130
	108. 651
Free ammonia.....	. 01
Albuminoid ammonia.....	. 005
Nitrogen as nitrates.....	. 900
Nitrogen as nitrites.....	None.
Oxygen consumed.....	4. 00

The volume of flow of the Poland Spring is reported to be about 8 gallons a minute. The temperature averages 42° and rarely varies 2° the year round. It is little affected by rain, and then only after the lapse of considerable time. The spring water is used for drinking at the Poland Spring House and the Mansion House near by and is bottled and shipped.

The Poland Spring is said to have been accidentally discovered in 1845. The hotel was built in 1876. In 1906 a fine plant, consisting of a spring house and bottling works, was installed at a cost of more than \$100,000. In the vicinity of the Poland Spring are situated a

number of other springs from which some water has been sold. One of these waters, sold near by, went for a while by the name of "Poliska water." Some years ago a well was sunk on the west side of the hill in an attempt to tap the Poland Spring, but without success.

Cliff Spring.—The Cliff Spring is situated one-fourth mile west of East Turner, and the water is sold in Lewiston. The flow is reported to be $1\frac{1}{2}$ gallons a minute.

Windsor Mineral Spring.—The Windsor Mineral Spring, owned by the Windsor Mineral Spring Company, of Boston, is situated 3 miles northeast of Lewiston post-office, on the slope of a rock hill which rises 100 feet or more behind the spring. The surface deposits consist of several feet of boulder clay. The water is said by the owners to issue from rock. The formation is pegmatite, gneiss, and schist. The slope of the hill is grassed over and covered in part by an orchard. The only buildings in the vicinity are a house and barn, situated 500 feet horizontally along the hillside, thus giving no opportunity for pollution by drainage. The flow is reported to be 5 or 10 gallons a minute and to be invariable. The temperature is said to vary 2° or 3° .

The water is sold in Boston, New York, and other cities for table and medicinal purposes. Some of it is carbonated. The charge for still water is \$1.50 a 5-gallon carboy. The spring is well protected by a cement curbing and is covered by a small spring house.

This water contains 154 parts per million of total solids. The complete analysis, recomputed according to the standard system, from the analysis reported in the company's circular, is given in the table (No. 208).

Lake Auburn Mineral Spring.—An important spring is situated on the northwest shore of Lake Auburn, at the foot of a gentle boulder clay and gravel slope, near the lake. Formerly the site of this spring was used for a summer resort and there was a large hotel here, but a few years ago the hotel was destroyed by fire and it has not been rebuilt. The spring is still covered with a small spring house, and many people from the village of North Auburn come here for drinking water.

PUBLIC SUPPLIES.

Several communities in Androscoggin County—Lewiston, Auburn, Mechanic Falls, Livermore Falls, Lisbon Falls, and Lisbon Center—have public water supplies. The last two mentioned are, however, the only ones using underground sources.

The village of Lisbon Center has a public supply owned by Mr. Herbert G. Spear, the water being derived from springs. The supply is distributed from a tank through galvanized-iron pipe, and the water is called good. The amount used per day is reported to be

1,500 gallons. The pressure is 15 pounds. The water mains are about 1 mile in length, and there are 30 taps. There is no fire service.

Lisbon Falls obtains its supply by direct pressure from two springs owned by the Sylvester Aqueduct Company.

CUMBERLAND COUNTY.

GENERAL DESCRIPTION.

Cumberland County lies in the southwestern part of the State, bordering on Casco Bay and extending inland toward the New Hampshire line. It has a length north and south of about 45 miles and a breadth east and west of about the same distance, and covers a total area of 1,014 square miles. The population according to the census of 1900 was 100,689. This county contains Portland, the largest city of Maine, which in 1900 had a population of 55,167. The county includes many large lakes, especially in the western part, the largest being Sebago and Long lakes and Thompson Pond. It contains nearly the whole of the Presumpscot River system, Saco River follows the western edge for 16 miles, and Androscoggin River near its mouth borders the eastern corner for a similar distance. The county is relatively hilly, ranging in altitude from sea level to more than 1,300 feet above sea level in the northwestern part. Along the coast are scores of islands, large and small, which are utilized extensively as summer resorts. A map of Cumberland County, showing the distribution of deep wells, important springs, and communities having public supplies, forms Pl. XII.

In the interior districts of Cumberland County the prevailing type of well is the old-fashioned dug well, but in the vicinity of Portland and on the various islands of Casco Bay drilled wells are abundant and are generally successful. The range in depth is from 30 feet to more than 800 feet, the most common depth being between 50 and 100 feet. A few drilled wells in the vicinity of Portland and a number of driven wells on the flood plain of Androscoggin River near Brunswick overflow.

UNDERGROUND WATERS.

RELATION TO ROCKS AND SURFACE DEPOSITS.

Character and distribution of rock types.—As in Androscoggin County, the prevailing type of rock is granite. Only the region in the southern part of the county, lying between Sebago Lake and the sea, and small areas along the coast and on the islands, consist of slate and schist. These areas include Portland, Cape Elizabeth, Scarborough, South Portland, Gorham, parts of Windham, Westbrook, Deering, Freeport, and the island portions of Cumberland and Yarmouth. In the extreme northeastern part of the county, in much of Harpswell and in the eastern half of Brunswick, is an area of "complex" in which

2

granites and gneisses alternate with slates, schists, and other rocks. which can not be subdivided in mapping.

Along the coast between Cape Elizabeth and Brunswick the rock varies in nature from hard, gneissic, and locally almost granitic rock to a very soft and schistose formation. The prevailing strike is north-eastward, and this peculiarity accounts for the northeast-southwest elongation of the islands in Casco Bay. In general, the stratification and cleavage coincide rather closely in strike, although they may vary considerably in dip. Here and there the strata are much contorted, but the cleavage is generally rather uniform and for the most part nearly vertical, although in places it is considerably inclined. On Peaks Island the strike averages N. 40° to 60° E., and the dip ranges from 30° to 60° NW. The cleavage there is parallel to the dip. In many places the cleavage planes are open and would seem to allow opportunity for considerable water to penetrate downward into the rocks.

The mainland of Portland and parts of Deering and Westbrook differ considerably from the coast and islands, being composed of nearly pure slate which shows little trace of schistosity. This is the general type of slate found farther inland in Maine. In Portland and vicinity the slates are cut by intruded trap and granite dikes. At many places near its borders the granite contains masses of slate, and, like the slate, it is cut by dikes of trap. This indicates that the slate was the first rock formed, that is was intruded by great masses of molten granite, and that later both slate and granite were intruded by small masses of basic rock in the form of dikes which may now be seen cutting those rocks.

The joint cracks in the vicinity of Portland correspond in trend to those developed in other parts of the State. On the other harbor islands the main joints trend approximately N. 30° E., and N. 70° W. At Woodfords they are irregular. Some are nearly vertical, and the most persistent hade is toward the northwest, but a few vertical joints run in an east-west direction. One of the best exposures of this slate can be seen in a large ledge at Fish Point, in the Grand Trunk Railway yards at Portland.

On the islands in Casco Bay the cleavage is inclined at a high angle with the stratification, the latter being much contorted. In places the cleavage and stratification correspond, but such agreement is generally accidental. The strike of the cleavage is N. 40° E., and the hade is from 30° to 90° NW. In places the rock is very shaly. The joint cracks at these places are very irregular, but one system runs between N. 20° W. and N. 50° W. These joints are rather numerous, but not persistent. The rock contains a great many quartz veins.

The structure of the slate and its adaptability for holding water are shown by phenomena recorded in the drilling of wells at Portland.

In one well the drill dropped several inches when water was struck at a depth of 288 feet.

Surface deposits.—The surface deposits of Cumberland County are very diversified in nature. In the towns bordering the coast there are large areas covered by clay, which in many places is in turn overlain by flat sand deposits. The upper surface of the clay is not flat but undulating, so that the overlying sand is not everywhere of the same thickness. Along the coast the clay does not in general rise more than 60 feet above tide, but in the valleys of Presumpscot and other rivers it is in places as high as 150 feet. The clay and sand plains are several square miles in extent. The clay is also underlain in many places by sand and gravel in which water may generally be found. A typical section showing the relations of the clay to the other deposits is exposed at Portland.

Typical section of drift at Portland.

	Feet.
Dark-brown clay with a few boulders.....	10
Fine stratified sand.....	8
	18

Another type of section is as follows:

Section of drift near Westbrook.

	Feet.
Coarse heterogeneous gravel.....	5
Stratified dark-brown clay.....	6
Fine horizontally-stratified sand.....	3
Coarse semistratified gravel.....	5
	19

The following section is exposed in a cut in Munjoy Hill on Washington street, Portland:

Section on Munjoy Hill, Portland.

	Feet.
1. Coarse gravel.....	3
2. Stratified gravel.....	10
3. Stratified, contorted, and eroded clay.....	5
4. Hard blue boulder clay.....	10+
	28+

On top of No. 3 in this section a large amount of water can be seen seeping out of the hill. On the east side of the hill there are great gullies from which springs issue, apparently on top of the same bed. As a reservoir is situated on the summit, it is possible that the water has its source in leakage.

A few exposures in the city of Portland show that the upper part of both hills on which the city is built consists of gravel, while rock forms the core at depths of 100 feet or so below the summit. Considerable areas in Portland outside the peninsula consist of clay rising to a maximum height of 100 feet above tide. Generally these clays

are underlain by sand or gravel which may contain water. In some of the brickyards considerable water seeps out of the clay near its base. The top of Bramhall Hill is reported to have once been a swamp, and the water which seeps out around both sides of the hill probably comes from this source. Springs are reported to have once been abundant on this hill.

Away from the coast the drift is thinner. On the highlands it is generally of the ordinary type of boulder clay, from 1 to 10 feet or more thick. About Sebago Lake, however, and in some of the broader valleys there are flat sand deposits of considerable thickness. Some undulating sand and gravel deposits are found on the highlands.

Buried valleys.—In most places the stratified drift deposits are underlain by rock at no considerable depth. Elsewhere, however, along ancient buried river valleys, the clay is of great thickness. Such a structure is found underneath Fore River between Portland and South Portland, where borings made during the construction of Vaughan's bridge showed the bed rock descending with a fairly regular drop from sea level at Portland to 110 feet below tide on the South Portland shore. A short distance south of this place the rock reaches the surface again and outcrops near Cape Elizabeth depot. In the construction of Vaughan's bridge two rows of 13 borings each were put down as tests. A sample record of the strata passed through is as follows:

Record of boring at Vaughan's bridge, Fore River, Portland.

	Feet.
1. Water.....	11.9
2. Soft black silt.....	21.4
3. Soft silty sand and peat.....	21.0
4. Very soft blue clay with silt.....	52.8
5. Coarse gravel and sand, hard.....	2.4
6. Slate.....	109.5

No. 3 is nearly pure peat in some borings; in others it is made up largely of sand. It is reported in only 10 out of the 26 borings, and when mixed with sand has a thickness of 5 to 30 feet, rising within 33 feet of mean low water. No. 4 is typical blue clay, and its surface rises from 55 feet below tide at South Portland to low-water level at Portland. No. 5 is a stony boulder clay.

The two kinds of buried valleys, those in the clay surface and those in the underlying bed rock, indicate that Fore River was the outlet for a stream of some size both before and after the deposition of the clay. It is probable that rock valleys of this kind extend many miles inland at several points along the coast, although they can not be traced on the surface owing to the great thickness of glacial drift. It may be expected that water supplies will be found by drilling wells in these filled valleys at some distance back from the coast.

WELLS.

GENERAL DESCRIPTION.

Types of wells used.—In Cumberland County, as nearly everywhere else in Maine, open wells are by far the most abundant type. The most common depth is probably 25 feet, and the wells are usually dug in boulder clay or gravel. As a rule they are fairly successful, but the quality, volume, head, and persistence of the water vary greatly. A few wells, such as some of those driven on the flood plain of Androscoggin River for the towns of Brunswick and Topsham, obtain flows of water from a depth of 25 to 35 feet. This is possible only in a few favored localities. In some localities wells driven through soft clay into the underlying sands and gravels obtain water of good quality. Drilled wells are generally successful.

Drilled wells.—In Cumberland County there are no deep wells sunk exclusively in drift; however, the borings for Vaughan's bridge in Portland go to a depth of 110 feet below tide before striking rock. This suggests the possibility of getting water along similar buried valleys. It may be worth while to mention the case of the Merrimac Valley in Massachusetts, where a number of wells were drilled into the gravels underlying the clays at considerable depths and a few flowing wells were obtained. Although there is no certainty that similar wells could be obtained in Maine, it is probable that wells sunk at any point along the old valleys would obtain plenty of water.

In Cumberland County the number of drilled wells which have been sunk is somewhat over 120. The diameter of these wells varies from 4 to 8 inches according to the situation and the quantity of water desired, but the common diameter is 6 inches. The depth ranges from 40 feet in a few wells to 830 feet in an unsuccessful well drilled at the Maine General Hospital.

Quantity of water.—The most common depth of well is 50 to 100 feet, and the depth to the principal vein of water is generally within the same limits. Some wells, however, find the principal water vein as deep as 200 feet. The wells are most closely grouped at Portland and on some of the islands in Casco Bay and in the town of Standish. Most of them are successful, although in a few no water was obtained, and a few wells are reported along the coast in which the only result was salt water which had probably penetrated inward from the sea. The quantity of water found varies greatly, from less than a gallon to 60 gallons a minute. The common capacity is not more than 10 gallons a minute. The best wells known in the county are at Portland. Generally the wells are permanent, but it has been necessary to drill a few of them deeper, and some have been abandoned because of decrease in supply.

Quality of water.—As elsewhere in Maine, the quality of the water is dependent largely on the kind of rock in which the well is drilled. It is found that the lowest amount of total solids is generally obtained from granite, although typical hard blue slate of the type found on the mainland at Portland generally gives water of moderate mineral content. Where the rocks are more schistose, however, and especially where they are mixed with trap and granite, approaching the type known as "complex," the water is of poorer quality, generally being higher in sulphates and carbonates and more commonly containing iron. There is probably no place in Cumberland County where the water is so highly charged with mineral matter as to be unsuitable for use in boilers, but sea water has penetrated and ruined a few wells. Generally the well waters of this county are low in mineral matter, and where kept safe from pollution by organic matter they are perfectly satisfactory for drinking. The table of analyses on pages 77–83 shows that the total solids in rock wells in this county run from 25 to more than 600 parts per million, with one higher report (2,008) due to sea water. The ordinary amount of total solids is from 100 to 150 parts, and the hardness from 16 to 176.

Uses.—Most of the wells in Cumberland County are used for domestic supplies. In Portland, however, they are used in several office buildings for both drinking and boilers and in a number of factories. On the islands of Casco Bay they are used to supply summer cottages. Several of these islands have installed public supplies from rock sources. Brunswick has a supply from deep wells in gravel and sand. Most of the wells of the county are pumped by hand or by windmill, but those used for public supply and some private wells are pumped by power. Several of the forts in Casco Bay are supplied by wells.

Flowing wells.—In Cumberland County 10 flowing wells are reported, exclusive of the wells of the Brunswick and Topsham water district, which flow at times. Most of these are situated on the islands of Casco Bay, but one of them is in Gorham and one in Westbrook. The greatest head is about 3 feet above the surface, and the greatest yield is about 2 gallons a minute. With few exceptions the water is suitable for any use.

DETAILED DESCRIPTIONS.

City of Portland.—The drinking-water problem is not pressing in the city of Portland, for the reason that an excellent supply is obtained from Sebago Lake, a body of water so large that it is little affected by any polluting influence. However, the number of summer cottages and hotels situated on the lake and its tributaries is increasing rapidly, and several steamboat lines are run regularly on the lake. It is feared, therefore, that the water may in time become dangerous if no precautions are taken to stop the increase of contaminating

influences. (See p. 125.) But at present the water supply of the mainland portions of the city is excellent, and the advantage of wells lies principally in a saving of water bills. Several companies and individuals have drilled deep wells for that reason, and on the islands of the harbor a number have been sunk for supplying summer cottages. In all, more than 30 drilled wells have been sunk within the city limits.

The deepest well known to have been drilled in the State of Maine was sunk in 1902 at the Maine General Hospital, on Western Promenade, overlooking the union station. This well was sunk to a depth of 830 feet. It was drilled by an experienced driller, who contracted to supply 16 gallons of water a minute, the price of the well being \$2,000. Only 3 gallons a minute were obtained, and this was not sufficient for the hospital needs. The driller requested permission to "shoot" the well with 200 pounds of dynamite, but his request was refused and the well was abandoned.

This well was situated 150 feet distant from a successful well 505 feet in depth at the same hospital, which obtained 13 gallons of water a minute and cost \$3,290, including the engine and pump. This well was sunk in 1902 to a depth of 100 feet. A year later it was deepened to 505 feet, its present depth. The first 24 feet of this well is through gravel, the next 76 feet through clay, and the rest through slate. It yields more than 21,000 gallons of water a day, and the water is of very good quality. The analysis (No. 45) shows 177 parts per million of dissolved solids. The sanitary analysis showed the water to be perfectly safe.

In the well drilled for Mr. D. F. Emory the following strata were encountered:

Record of D. F. Emory well, Portland.

	Feet.
Fine sand.....	12
Gravel and sand.....	30
Hard "sandstone".....	10
Rock.....	76
	128

In a 298½-foot well belonging to Burgess, Forbes & Co. the strata were as follows:

Section of Burgess, Forbes & Co. well, Portland.

	Feet.
Gravel.....	14
Clay.....	65
Clay and gravel.....	18
Clay.....	52
Slate.....	61
"Granite".....	88½
	298½

If the "granite" is really granite, it indicates the extreme irregularity in distribution of this rock beneath Cumberland County.

One of the best wells in the city is that belonging to Mrs. Mary J. Frazer, at the corner of Franklin and Fore streets. This is a flowing well 210 feet deep, in slate. It is pumped by a windmill and is reported to yield 25 gallons of water a minute and to supply drinking water for a large number of tenements in the vicinity. Water was obtained at a number of different depths, but the best vein was tapped at the bottom of the well. The owner reports the use of this well as a great saving in expense over city water. It is a fine, clear water, and contains 25 parts per million of total solids, a lower amount than exists in the water of any other deep well in the city. An interesting feature regarding this well is that although it is situated but a few hundred feet from the sea, where the normal amount of chlorine is over 6 parts per million, only 1.4 parts of chlorine were found in this water. This may mean that the water comes from a source some distance inland.

An unsuccessful well was drilled in 1887 for the Consolidated Electric Light Company of Maine, on Plum street. This well is 8 inches in diameter. Salt water was struck at 140 feet from the surface, and the well was drilled to 204 feet in the hope of getting water of better quality. It yielded 65 gallons a minute, and the well could not be pumped dry, but the water was too salty for use. The well was then plugged at a depth of 145 feet. An analysis was made, and the result showed the total solids to amount to 2,008 parts per million, of which 1,912 were readily soluble and 96 insoluble by heating. The water was rather alkaline and contained a trace of iron. The analyses showed that there was less calcium carbonate than before plugging and that nearly all the magnesium carbonate was shut off; the sodium chloride increased considerably. The water has great tendency to scale and corrode the boilers. As the total solids in this water do not approach the amount in sea water, it can not be pure ocean water, but is considerably diluted with rock water.

Another unusual well is the one belonging to Mr. James P. Baxter, at Baxter Block. Mr. Baxter reports his well water to be better than Sebago water, because the latter will show a slight sediment on standing, whereas that from his well will not. This well nearly flows. It is said that when the drilling had reached a depth of 76 feet no water had been found, but at that depth the drill suddenly dropped for a distance of more than 80 feet through a cavernous space. If this report is accurate, it is probable that a vertical joint crack of considerable size was encountered.

The well drilled for E. T. Burrowes & Co. is 106 feet deep and becomes a flowing well in the spring. Analysis of this water showed pollution by sewage, and it is not used for drinking.

On account of the general use of Sebago water in Portland there are few dug wells within the city limits. The former town of Deering now belongs to Portland and has for years used the city supply. There are a few dug wells in the vicinity of Woodfords, but these are not used for drinking water, as the population has become too dense to make water from shallow wells safe. In quality the Portland water is very good, as regards both purity from pollution and low mineral content. The analyses of waters from 11 deep wells in the city are given in the table (Nos. 37 to 47).

Peaks Island, Portland.—The shore of Peaks Island consists almost entirely of bare rock and bowlder clay, but the interior, rising at points to a height of more than 80 feet above tide, is covered in places by sand and clay which are locally 20 feet or more in thickness. The rock consists of slate and sandy schist striking northeast and having a nearly vertical dip. In hardness the rock varies greatly, as it is cut by a great many small veins of quartz.

There are many open wells on the island, the most common depth of which is 15 feet, and these generally afford plenty of water. The capacity of some of them has been increased by blasting a few feet in ledge. On account of the increasing summer population of the island surface wells are no longer safe. Wherever practicable their use should be discontinued and deep wells or the public supply be substituted.

Drilling on the island is comparatively easy, and a number of deep wells have been sunk. Their depth ranges from 45 to more than 200 feet. The best wells on the island are the two drilled for the Peaks Island Water and Light Company, which are 202 feet deep. These wells are connected by a natural fissure below the surface and together will yield 85 gallons a minute with the pumps running twenty-four hours a day.

On Peaks Island there is one flowing well, belonging to Mr. C. W. T. Goding, of the Casco Bay Steamship Company. The mouth is only a few feet above tide. This is an 8-inch well, 135 feet deep. By pumping, it yields 52 gallons of water a minute. No failures are known on the island, but two or more wells obtain only 2 or 3 gallons a minute each. A few people have used springs, but these are now abandoned. Two analyses of deep-well waters on this island are given in the table (Nos. 35 and 36).

Great Diamond Island, Portland.—The surface of Great Diamond Island is mostly bowlder clay, with slaty ledge outcropping in a few places. The west side of the island is low; the east side is high and rocky. The rock is similar to that on Peaks Island, but is more slate than schist. Many wells here, even including two of those belonging to the water company, are only open wells a few feet in depth, some of them blasted 2 or 3 feet into the ledge. Two wells drilled

on the western shore for the Diamond Island Association were successful; they yield 12 and 15 gallons a minute and now supply about 60 buildings, mostly cottages. The water is found at a depth of about 100 feet in gneiss. Analysis No. 31 gives the composition of water in one of these wells, and No. 32 is a field assay from the other.

At Fort McKinley, on the north end of Great Diamond Island, seven wells have been drilled at various times for the United States Government. They range from 95 to 302 feet in depth, and water is found at depths of 80 to 100 feet. Two or more of them were abandoned because of insufficient supplies, but the rest yield a maximum amount of 4 to 40 gallons a minute. The detailed description of these wells may be of benefit in future deep drilling on neighboring islands.

Well No. 1, 97½ feet deep, overflowed the surface before pumping. The test showed 25 gallons a minute. Well No. 2, 95 feet deep, situated 150 feet east of No. 1, taps the same vein, and before pumping the water overflowed the surface. In the test it showed 30 gallons a minute by pumping, and when pumped with No. 1 it will supply 48 gallons a minute. Well No. 3, situated 150 feet south of No. 1, is 265 feet deep. The test showed 15 gallons a minute. Well No. 4, situated 300 feet northwest of No. 1, is 302 feet deep and supplied 14 gallons a minute in the test. In wells Nos. 3 and 4 the water stands at 15 to 20 feet below the surface. The pumps are down 125 feet and 150 feet, respectively. In these wells 15 to 18 feet of drift was penetrated on top of the rock; the remainder is schist, much of which contains pyrites. The total capacity of all four wells during the wet season of 1902 and 1903 was 84 gallons a minute. The total capacity during the dry season of 1904 and 1905 was 30 gallons a minute. In dry seasons wells Nos. 1 and 2 can be exhausted.

Little Diamond Island, Portland.—Little Diamond Island is situated just south of Great Diamond and is connected with it at low tide by a sand bar. So far as the structure of the rocks is concerned, it is but a continuation of Great Diamond Island. On Little Diamond one well has been drilled to a depth of 170 feet and obtains 4 gallons a minute from 160 feet below the surface. Most of the wells on this island are dug wells less than 20 feet in depth. These are perfectly safe if situated on the uphill side of all houses. At the east end of Little Diamond Island is a light-house at which the Government has a well 171 feet deep. The water in this well is salty and contains total solids amounting to 460 parts per million, the chlorine being 397 parts, carbonates 80 parts, and sulphates also high. The unusual composition is due probably to a considerable admixture of sea water.

House Island, Portland.—House Island consists of solid rock round the sides, but there is some drift on top. On this island a single well was sunk to a depth of 170 feet. It is reported to supply 15 gallons a minute.

Cushing Island, Portland.—Cushing Island is the most southerly of the group of islands in Portland Harbor, and is about a mile in length. The cover, of till, is 1 to 5 feet or more in thickness, and the underlying rock is schistose gneiss of varying degrees of hardness. This island is a better collector of water than some of the others, because it has a few depressions in the surface and less bare rock. The principal system of joint cracks here strikes N. 40° to 50° W. and has a dip N. 25° from the vertical, the joints being from 3 to 10 feet apart. A second system strikes N. 80° W. to N. 70° E. and has a dip N. 10°. The third system, probably sheet joints, strikes north and south and dips toward the west at 20° to 30° from the horizontal. Along the shore a great many irregular joints can be seen.

On this island there are several private wells which strike water at depths of 80 to 275 feet, and the United States Government has drilled four or more wells at Fort Levett. There are a few dug wells on the island, but most of the residents use water from a drilled well belonging to Mr. Cushing.

The most extensive drilling on the island was for Fort Levett. Here several wells have been sunk and abandoned. Official records have been kept of only the three most recent ones. Well No. 1 struck rock at 18 feet and was cased to 28 feet. Its total depth is 277.2 feet. A forty-eight hour test on January 4, 1906, showed 30 gallons of water a minute. The rock resembles hard mica schist or quartzite. The pump barrel is down 150 feet. When pumped the water falls below this level. Well No. 2, drilled in 1906, is 326 feet deep. It penetrates 11 feet of soil and clay and is cased to a depth of 74 feet. The water level before pumping stands within 20 feet of the surface, but while pumped it stands 300 feet lower. On the test this well supplied 10 gallons of water a minute, but this was not considered enough, and a new well was drilled. Such a well should not be abandoned, as 10 gallons a minute is a good yield in Maine. Well No. 3 struck rock at 15 feet and is cased to 27 feet. The water stands 20 feet below the surface. On January 3, 1907, it was 176 feet deep, but no report has been obtained since it was completed.

Long Island, Portland.—The rock on Long Island is mostly schist, which splits easily along the bedding planes, standing nearly vertical. The island contains a great many cottages, but no public supply is used. The only wells are of the old-fashioned open type.

Cow Island, Portland.—A flowing well is reported to have been drilled at Fort Lyon, on Cow Island, in 1906. The natural flow was 6

gallons a minute, and the capacity by pumping is reported to be 40 gallons a minute.

Gorham.—A number of drilled wells have been sunk in the town of Gorham, and so far as known they have been successful, as regards both quality and quantity of water. The deepest well is that of Mr. J. H. Rines, in the eastern corner of the town. This well was drilled all the way in solid rock. The drilled wells are about a dozen in number, and range in depth from 40 to 307 feet, generally supplying enough water for domestic purposes from a formation which is mostly slate. In the eastern part of the town the dug wells average 15 feet in depth and contain, as a rule, 5 or 6 feet of water in the dry spell, though some of them dry up. One dug well is more than 60 feet deep, in till, and for fifty years has never been known to be dry. The analysis of water from a 66-foot rock well is given in the table (No. 30).

Westbrook.—The formation at Westbrook is for the most part slate, but the northern part of the town is underlain by granite. The bed rock is only a few feet below the surface. In that section the wells are open wells, only 10 to 20 feet in depth. Many wells go dry during the summer, but those blasted a few feet in ledge give plenty of water.

In the vicinity of Saccarappa there are two flowing wells, one owned by Mr. Rufus Jordan, the other by the Haskell Silk Company. These wells are both 216 feet in depth and obtain their flows near the bottom of the well. The surface rock is slate, but one or both wells are reported to enter granite. It is possible that the flow may be caused by the penetration of water downward from the hills along the contact between the granite and the slate, but this conclusion has not been definitely proved. The composition of the water in the flowing wells is given in the table (Nos. 51 and 53).

Chebeague Island, Cumberland.—Chebeague Island is the largest of the islands in Casco Bay, being more than 3 miles in length. Like other islands of the bay, it consists mostly of schist, but the surface of the interior is made up in part of sand. It is easy to get water from shallow wells, and for that reason only one drilled well has been sunk on the island. The depths of the dug wells are only 6 to 20 feet. The water is mostly safe for drinking. The abundance of water on this island is due to the thickness of the drift covering and to a swampy depression which lies on the high land of the interior. The only drilled well is owned by Mr. E. A. Ballard. This well was drilled to a depth of 52 feet and obtained plenty of water. Later it was sunk to 80 feet, and still later to 301 feet. The latter extension was unsuccessful, not increasing the supply. The water is good and clear, and the supply has increased in volume through natural causes since the well was drilled. The amount is small, but is sufficient for domestic purposes at the cottage.

Little Chebeague Island, Cumberland.—Little Chebeague Island bears the same relation to Chebeague Island that Little Diamond Island bears to Great Diamond. Little Chebeague is connected with the main island at low water by a sand bar. All over the island the drift is thick, 40 feet or more of it being exposed in a nearly vertical cliff on the north side. On top of this bluff, not many feet from the edge, a well was drilled to a depth of 197 feet. Rock was struck at about 100 feet. The water is good and was at first plentiful, but the supply has diminished until now there is not enough to supply one family. Another well should be drilled to the east of this, and it is believed that there is an even chance of obtaining a better well. On this island a dozen or more cottages use open wells.

Windham.—The town of Windham is rather hilly, and the rock consists mostly of slate and schist. The wells are nearly all open wells, 10 to 40 feet in depth, but at South Windham two drilled wells have been sunk. One of these was a failure owing to improper casing; the other well supplies plenty of water for three or four families. Most of the people in the village use Sebago Lake water, as the Portland aqueduct runs near the village. A few springs emerging from gravel have been used in the vicinity, and the mills obtain water from this source. There is plenty of water in the gravel, and its quality seems to be very good. Some of the dug wells run dry during the summer.

Scarboro.—The greater part of the town of Scarboro consists of broad sand and clay plains rising from sea level to 100 feet or more above tide. On these plains the water level is only a few feet below the surface and excellent soft water can generally be obtained by driven wells, at a cost of only \$12 to \$15. The size of pipe commonly used is 1½ inches.

In this town drilled wells are generally unnecessary, but on the hills and in some localities where the rock approaches the surface it is necessary to drill. On the road running from West Scarboro to Portland several wells have been drilled, which range in depth from 50 to 200 feet. They generally yield plenty of water for a house and farm. One of them, on the H. J. Libbey estate, gave 3½ gallons a minute for three and one-half hours in the test. In this part of town there are a number of dug wells 15 to 20 feet in depth. The formation on the hills and underneath the drift is slate.

In West Scarboro the deep wells are good, but most of them are less than 50 feet in depth. A number of springs in the vicinity are used to supply houses in the village. Some wells are bored in clay, and a few of these have been unsuccessful. Most wells here, however, supply enough water for a family from a depth of 30 to 35 feet. The best water is obtained by penetrating the clay.

At Pine Point Beach the wells are only 10 to 15 feet deep, driven in sand. On Blue Point Hill the wells are all dug, and some of them fail in summer. On Prouts Neck the formation is all rock. Conditions there have not been investigated, but it is probable that water can be obtained by deep drilling.

Cape Elizabeth.—The coast of Cape Elizabeth is very high and rocky and is greatly appreciated as a summer resort. The few wells that have been drilled along the coast range in depth from 60 to 120 feet, supplying summer cottages. The Shore Acres Land Company, however, has a well 151½ feet deep, which supplies a number of houses with good water. Away from the coast the wells are mostly shallow and are driven or dug in sand and gravel. In quality the rock water is generally good. An analysis of water from a 115-foot well at Cape Cottage reports 140 parts per million of total solids. The calcium here is 43 parts per million, which is high for southwestern Maine.

South Portland.—The coast of South Portland is mostly bold and rocky, like that of Cape Elizabeth. The surface varies from rocky hills to plains of clay overlain by sand. Nearly the whole town uses Portland water, and there is little demand felt for drilled wells. Several shallow wells on the clay plain penetrate the underlying gravel and obtain water of good quality. No drilled wells are reported. An interesting set of borings made for Vaughans Bridge is described under Portland (p. 107).

Falmouth.—The surface of Falmouth is made up of clay and sand plains rising to an altitude of 100 feet, broken by low hills of schist and granite. Throughout the town the wells are shallow and the conditions are variable. Part of the town is now using Sebago Lake water. In the southern part a number of drilled wells have been sunk, some of them more than 100 feet, and the chances for water have been found to be fairly good.

At Falmouth Foreside the Underwood Mineral Spring is situated.

Clapboard Island, Falmouth.—On Clapboard Island a single well has been drilled by Mr. S. F. Houston. It reached a depth of 210 feet. No information regarding this well has been received.

Standish.—In the town of Standish much drilling has been done, 18 wells having been put down by a single driller. The wells range in depth from 40 to 90 feet. The drilled wells are mostly open wells which have been deepened because of previous insufficient supply. The volume of water is still small, but is sufficient for all farm purposes, in some wells amounting to 10 gallons a minute. Some of these wells can not be pumped dry, but most of them are exhausted in a short time.

The well of Mr. Frank H. Rand was originally a 30-foot open well, blasted 22 feet in ledge. There was little water, and the owner

drilled to a depth of 60 feet, striking a pocket of water, which soon gave out. The well was afterwards deepened to 79 feet and obtained 10 gallons a minute. Most of the wells have been drilled in rock, but several near the village of Sebago Lake penetrate nearly 40 feet of sand. As a rule the water comes from crevices in a schistose rock. One shallow drilled well in Standish contained so much iron that it was not used. The only evidence of the composition of water in this town is derived from a field assay (No. 50).

Bridgton.—The town of Bridgton is believed to be entirely underlain by granite. In the village and town much drilling has been done at various times, 14 wells having been sunk by one driller. The depths range from 40 to 290 feet. So far as known, the wells of moderate depth have been successful, and a 200-foot well seems also to have been satisfactory. A well 290 feet in depth, however, was drilled for the Bridgton Aqueduct Company and yielded very little water. This is one of many examples showing the uselessness of sinking wells below 200 feet or so in granite. At North Bridgton and elsewhere wells are dug and seem to be mostly satisfactory. Several field assays (Nos. 3, 4, 6, and 7) of water from Bridgton wells have been made, but only one complete analysis (No. 5).

Harrison.—Several wells have been drilled at various times in the town of Harrison, one of them, high on a hill, being 90 feet deep and successful. Other wells—as several at Bolsters Mills—were only about 40 feet deep and obtained water, but were abandoned in favor of a spring supply which is now used by that village. On the hills many people use excellent springs which issue from bowlder clay and are pumped by windmills to houses higher up.

Otisfield.—Several drilled wells have been sunk in Otisfield, and the conditions seem to be favorable for obtaining underground-water supplies, but no data are at hand.

Brunswick.—Brunswick is an example of a city with a good water supply, taken from driven wells on the flood plain of Androscoggin River, as explained under the heading "Public supplies." Formerly the river water was used and typhoid fever was epidemic; later the water was purchased from Bath. So far as safety is concerned private wells are now unnecessary. In case individuals or companies desire to sink wells, they will probably succeed in getting sufficient water, either from shallow wells sunk through the surface sands and clays into underlying gravel or by drilling into rock. The former source is recommended for manufacturing establishments in situations where the surface deposits are of sufficient thickness.

Harpwell.—This part of the Maine coast is so uniformly rocky, and it is so difficult to get water from dug wells, that many people at their summer cottages have resorted to the ancient custom of using cisterns and rain water. Few people in Harpswell use drilled wells.

At the extreme end of Mere Point is one well 67 feet deep, in schist, which furnishes enough water for all the families—a dozen or more—having cottages on the end of the point. An analysis of the water from this well is given in the table (No. 33).

Freeport.—The public supply of Freeport village comes from Frost Gully Brook. In the town a number of wells have been drilled to depths varying from 100 to 200 feet. They could not be pumped dry during a twenty-four-hour test and were used for some time, but were abandoned when the public supply was instituted. The well water is obtained in gneiss. Several wells at South Freeport, about 100 feet deep, obtain enough water for domestic uses from granite. Casco Castle at South Freeport obtains its supply from a spring situated 2 miles south of the hotel. Otherwise South Freeport uses shallow wells.

Other towns.—In the towns of Baldwin, Sebago, Naples, and New Gloucester some drilled wells have been sunk, but they are rare and scattered. In Casco, Raymond, Pownal, Gray, and North Yarmouth no drilling is known to have been done, and only open wells, with perhaps a few driven wells, are used.

SPRINGS.

General statement.—In Cumberland County springs are abundant. The topography is varied, the covering of drift is in many places thick, and springs seep out along the boulder-clay hillsides. In the country districts water is pumped from some of these springs by windmills or hydraulic rams to houses on the hills above. Where springs are not situated within limits of pollution from neighboring houses the water is generally of good quality. One small village—Bolsters Mills—uses springs for a public supply. In many parts of the region covered by clay and sand plains it is common to find springs emerging from sand overlying clay. Some of these springs contain surprisingly small amounts of mineral matter and many are entirely free from organic matter.

The commercial mineral springs in Cumberland County which report sales are as follows:

Paradise Spring, Brunswick.

Pownal Spring, New Gloucester.

Raymond Spring, North Raymond.

Underwood Spring, Falmouth Foreside.

Paradise Spring.—Paradise Spring is situated in the eastern part of the town of Brunswick and is owned by D. D. Gilman & Bro., of Brunswick. It is renowned as having been a favorite resort of Nathaniel Hawthorne. The spring lies at the foot of a steep sand bluff, rising above the flood plain of Androscoggin River, not far from the waterworks of the Brunswick and Topsham water district. It is

supposed that the spring water percolates out of the sand above its contact with the clay, as seen in a number of roadside springs in the vicinity. The water is colorless, odorless, and tasteless. It has a temperature of 43° in winter and 45° in summer, and the stream coming out of the small pipe in the bank is reported by the owners to supply about 8 gallons a minute. This yield is said never to vary. The surroundings are wooded, and there are no buildings in the vicinity, so the spring is perfectly free from danger of pollution. The chemical composition is reported in analyses 217 and 218, recomputed from those reported in a circular issued by the owners. The total solids are only 18 parts per million.

Formerly Paradise Spring water was sold in Brunswick, but since the new city water system was installed there has been no demand for mineral water and the owners have gone out of the business. The price at which it was marketed was 75 cents a 5-gallon carboy. There is no spring house or other improvement at the spring.

Pownal Spring.—The so-called Pownal Spring is situated at New Gloucester, on rather high land, and there is believed to be no chance for pollution. The water is reported to flow from solid rock. Some years ago the Pownal Spring Hotel Company was incorporated and the water was analyzed with a view to establishing a hotel near the spring. The analysis, as recomputed from that reported in the company's circular, is given in the table (No. 221). The total solids amount to only 20 parts per million. The owners claim valuable medicinal properties for the water.

Raymond Spring.—Raymond Spring, situated at North Raymond, about one-eighth mile northwest of North Raymond post-office, was for twenty years prior to 1905 known as Wilson Spring. It is reported to issue from a fissure in granite about 100 feet below the summit of a hill. Formerly there was a hotel here, but some years ago it was burned. The flow is large and is said to diminish only slightly in dry seasons. The water is clear and sparkling, odorless, and tasteless. As there are no houses near by, it seems to be perfectly safe. It is used for drinking and medicinal purposes and is shipped and sold at 30 cents a gallon. The owners claim medicinal properties for it. An analysis of the water reported in a statement issued by the owners, recomputed into ions and parts per million, is given in the table (No. 222).

Underwood Mineral Spring.—Underwood Spring is situated at Falmouth Foreside, a few feet above sea level and only a short distance from the shore in a gully, the sides of which consist of clay. It is owned by the Underwood Mineral Spring Company, of Portland. The water is believed to issue from sand directly on top of the clay. The spring is bricked up, and the upper of its two openings is covered by a large glass pyramid. The water is colorless, odorless, and taste-

less. The flow is reported by the owners to be 140 gallons a minute, and the measured temperature is 46°. A large hotel is situated on the sand plain above the spring, several hundred yards distant from it. The locality is used as a resort, and the water is bottled and shipped for medicinal and table use. A 5-gallon carboy delivered on the train or in Portland sells for 75 cents. "Soft" drinks are also made. The bottling house is situated on the shore of the bay and the water flows directly from the spring to this place. The mineral analysis of the water, recalculated from the analysis of the water reported by the owners, is given in the table (No. 219).

Summit Spring.—Summit Spring is situated on very high land in the northern part of the town of Harrison. It is the site of a hotel, and formerly was extensively used. The yield is reported to be 38 gallons a minute and the temperature 46°. The analysis shows the total solids to amount to 68.9 parts per million.

PUBLIC SUPPLIES.

General statement.—The largest water supply in Cumberland County comes from Sebago Lake, whence it is carried by an aqueduct to the city of Portland. The surrounding towns also use this water where the Portland aqueduct lines are conveniently situated. Of the 15 communities in Cumberland County which have public water supplies 7 are supplied from surface sources, 4 from wells, and 4 from springs. Six of the communities having surface supplies use Sebago Lake water. These are Portland, South Portland, Cape Elizabeth, Westbrook, Gorham, and Falmouth Foreside. Freeport obtains its water from a brook.

The most important underground-water supply in the county is that of Brunswick, which has combined with Topsham, in Sagadahoc County, to install a supply obtained from driven wells on the flood plain of Androscoggin River. Peaks Island, Great Diamond Island, and Cushing Island, in Portland Harbor, have public supplies from drilled wells. The communities using spring supplies are Yarmouth, Yarmouthville, Bolsters Mills, and Casco. All these supplies are described in detail below.

Brunswick and Topsham.—Formerly the public supply of Brunswick was taken from Androscoggin River, and typhoid fever was prevalent in the village. That system was abandoned, and until recently water was purchased from the Woolwich Water Company, which supplies Woolwich and Bath from Lake Nequasset, in Woolwich. This supply was regarded as unsatisfactory; consequently, in 1904 a water district was established, embracing the towns of Brunswick and Topsham, with a population of about 7,300 persons to be served, and a new source of supply was sought in driven wells.

A test well, driven to hardpan on the flood plain of Androscoggin River $1\frac{1}{2}$ miles east of the Brunswick post-office, yielded an abundance of good water. Thereupon a number of other wells were driven in the same vicinity, 50 of which constitute the source from which the supply is taken. These wells are situated along a straight line extending a distance of about half a mile on the flood plain, not more than 10 feet above the river. Back of them rise several terraces, the highest of which is about 60 feet above the surface on which the wells are situated. At the base and along the sides of these terraces are many springs, the best known being the Paradise Spring, described on pages 119-120. The flood plain is composed of recent river deposits and is in places marshy. The upper terraces are composed of marine clays overlain by sand. The water seems to follow the upper surface of the clay beneath the sands and gravels, seeping out wherever the covering is thin or broken and saturating the sands and gravels to such an extent that they form practically an exhaustless reservoir. The facts that the water surface in the wells is considerably higher than the surface of the river and that its analysis is different from that of the river water show that the latter is not its source.

The wells are all of about the same character. They are $2\frac{1}{2}$ inches in diameter, with a depth of 25 to 35 feet, depending on the height of the surface above the river. The principal water bed is very coarse sand from 5 to 10 feet thick, overlain by 15 to 20 feet of finer sand and 3 to 6 feet of sand and clay. Underlying the water bed is a considerable depth of "hardpan," consisting of clay and sand. A test well was driven 155 feet, when bed rock was apparently encountered, as it was impossible to drive farther. Under normal conditions the water in the wells rises within a foot of the surface, but in the spring and after heavy rains some of the wells flow, yielding about 5 gallons a minute. In order to estimate the capacity of the wells a test was undertaken, beginning September 21, 1904, and continuing night and day for thirty days. Nine wells were connected with a fire pump having a 10-inch cylinder and a 12-inch stroke. The result of the tests showed an average yield of 1,003,732 gallons daily. The total yield from the entire series of wells is estimated at about 5,000,000 gallons daily.

The water supplied by the wells is as soft and excellent in quality as any other public supply in Maine. Analyses, recomputed into ions and parts per million from those reported by the company, are given in the table (Nos. 177-179).

From the wells the water is pumped to a standpipe, 145 feet above the town, having a capacity of 650,000 gallons. The mains are $13\frac{1}{2}$ miles in length. There are 80 fire hydrants in Brunswick. The average pressure is 60 pounds. About 5,000 people are supplied with water.

Peaks Island, Portland.—A large part of Peaks Island is supplied by a water system owned by the Peaks Island Water and Light Company. The water is obtained from two drilled wells situated close together near the south end of the island, not far from the village. The wells are sunk in solid rock and are unusually satisfactory for drilled wells, as explained under the description of wells on Peaks Island (p. 112). They are pumped by two steam pumps. The test showed that 50 gallons a minute could be obtained from the older of the two wells, this being the full capacity of the pump. During the test the water surface was lowered 35 feet. The test of the newer well showed 110 gallons a minute for seven hours, when the water gave out. There is, however, a plentiful supply of water in the two wells, and they can be pumped together at the rate of 75 gallons a minute day and night. The water mains belonging to this company are about 7 miles in length. Two miles of these are "under frost," or buried deep enough so that they can be used during the winter. The other 5 miles are "above frost" and for the most part on the surface. The pipes used are 8, 6, and 4 inches in diameter. The owner, Mr. E. E. Rounds, reports that 255 takers are on his books. Most of these people are cottage holders, and they have unlimited use of the water at \$10 a year. Seven hotels are on the system, and some of these pay as much as \$100 a year. The water of the company has been analyzed, but the analysis has not been received by the Survey. From a sanitary standpoint the water is believed to be as pure as could be desired. The pressure on the main street is 60 pounds.

At the north end of Peaks Island there is a smaller system of waterworks, owned by the Beacon Hill Water Company, which has a drilled well 70 feet in depth pumped by a hot-air pump. More than 30 buildings are reported to be supplied by this system.

Great Diamond Island, Portland.—Great Diamond Island is largely supplied by a water system owned by the Diamond Island Association. The water is obtained from wells, 2 of them being ordinary dug wells and 3 others being drilled to a considerable depth in solid rock. The dug wells are little used, as the water has been found not very good. The drilled wells are pumped by hot-air engines and windmills. The supply is adequate for the island except sometimes in the summer season, when it is necessary to resort to private wells or to the surface wells owned by the company. It is supposed that about 60 cottages are supplied with water from these sources. The supply is satisfactory except that in summer the water becomes so warm, owing to the pipes being laid on the surface of the ground, that it is not used for drinking. In consequence of the position of the pipes the supply has to be discontinued during the winter. An analysis of water from one of the drilled wells is given in the table

(No. 31). Other data relative to the wells will be found on pages 112-113. From the wells the water is pumped to a tank situated on the hill in the center of the island, the capacity of the tank being 60,000 gallons and the pressure 30 pounds. A smaller tank is situated near by. There is no fire service. About 10,000 gallons a day are used.

Cushing Island, Portland.—A hotel, stable, and about a dozen cottages on Cushing Island are supplied by a 275-foot well owned by Mr. Francis Cushing. The water is pumped by a deep-well steam pump through 2½-inch pipe to three tanks on top of the hill. The well and pump are inclosed in a pump house, and the pump is operated eight to nine hours a day. At one time it was tested five days continuously without failure, and the yield was variously reported at 40 to 70 gallons a minute. The water is fine and clear and has a measured temperature of 52°.

Yarmouth and Yarmouthville.—These villages have a public water supply from springs belonging to the Forest Paper Company, but the system is owned by the town. The springs are reported to issue from sand at the base of a rocky hill at a rate of 100 gallons a minute. The water is distributed from a standpipe 100 feet in height and 50 feet in diameter, its capacity being 265,000 gallons. The pressure is 60 pounds. The water is good, and 130,000 gallons a day are used for farm and domestic purposes. There are 8 miles of mains, 800 taps, and 57 fire hydrants, and the system supplies 2,000 people. So far as known the supply is satisfactory. Royal River furnishes an emergency supply.

Bolsters Mills.—More than 20 families and the stores at Bolsters Mills are supplied by two springs situated just east of the village. The springs issue from boulder clay a few rods distant from the base of a high gravel moraine. The springs proper are dug holes, 3 by 3 feet in size and 2 feet deep, with an outlet pipe and strainer in the bottom. They are owned by Mr. Alfred R. Clark. The water is reported to be of very good quality; and as there are no buildings above, there is no chance of pollution. The springs are covered with protecting sheds.

There is plenty of water here for all purposes, but some care is necessary not to waste it in dry seasons. Water rates are \$6 a year for either one or two faucets. About two-thirds of the houses in the village use the public supply.

PREDICTIONS AND RECOMMENDATIONS.

In an investigation like that of the underground waters of Maine it is gratifying to see that in some districts the value of drilled wells is appreciated. In the vicinity of Portland a number of manufacturing establishments and tenement owners are using drilled wells and

thereby saving water bills. On the neighboring coasts and islands of the harbor there is a large summer population, and these people are using a great many drilled wells. Such is also the case in a few summer-resort districts away from the coast. In general excellent supplies of pure water are obtained, and very few failures have been encountered. The proportion of successful wells shows that there is plenty of water for domestic use in the rocks, although the supply is not always sufficient for hotels. As might be expected, there have been a number of failures, but the chance of success in any locality is far greater than the chance of failure. Drilled wells are so much safer and so much more satisfactory when an adequate supply is found that it would seem desirable to search for water in this way much more extensively than has been done.

The success of well drilling in the vicinity of Portland has been so marked that it seems safe to recommend sinking wells on islands of the harbor where as yet they have not been drilled. For example, on Long Island the residents are using the common open wells, as of old. A number of people on Peaks Island and some of the other islands use wells of the same type. These may be safe in the country, but are hardly safe in a summer-resort island having a large population. A public water system could be installed on other islands at a comparatively small cost, as has been done on Peaks Island and Great Diamond Island. The water obtained by deep wells will be safe for drinking, and three or four wells will probably give a sufficient supply for any of the largest islands.

It may not be amiss to emphasize in this connection a precaution regarding Sebago Lake water, to which reference was made on pages 109-110. This lake has for years been supplying the city of Portland and several adjacent towns, and the water has been found to be one of the best surface supplies in the State. There is more water than can ever be utilized, and the lake is so large that contaminated water now entering any particular part of it would be so diluted as to cause little danger to the inhabitants of the city. It must be remembered, however, that there are already a number of cottages and hotels along the shores of Sebago Lake and its tributaries, and that these are springing up more thickly every year. At least two steamboat lines run on the lake regularly, and it is used for fishing and bathing. Every precaution should therefore be taken to keep the lake in a sanitary condition and to prevent the increase of cottages and hotels along the shores. The best plan would be for the city or the State to acquire and hold the lake as a public reservation in care of a park commission, as has been done with several large reservoirs in Massachusetts and other States.

SOUTHERN FRANKLIN COUNTY.

GENERAL DESCRIPTION.

Franklin County is situated in western Maine, its north end bordering on the Canadian line and its west end separated from New Hampshire by a distance of about 12 miles. The county has a length from north to south of about 85 miles and an extreme width of 30 miles. Its total area is 1,764 square miles, and its population, according to the census of 1900, was 18,444, the least next to Piscataquis County. This county contains no cities or large towns; Farmington, the county seat, has a population of 1,251. Less than two-thirds of the county is situated in the territory covered by this report, but the region farther north contains few features of importance to a report of this nature. The county is one of the hilliest in Maine, and contains numerous lakes and ponds, of which the largest situated entirely within the borders of the county is Rangeley or Oquossoc Lake. A large lake, Mooselookmeguntic, lies on the boundary between Franklin and Oxford counties. A stretch of Androscoggin River, less than 5 miles in length, cuts across the southern corner of the county, and Rangeley and Mooselookmeguntic lakes lie near the headwaters of the same river, but with these exceptions there is no large stream within the borders of the county. Sandy River, a tributary to the Kennebec, flows through the south-central part of the county, and Dead River, with its numerous lakes and small tributaries, is a conspicuous feature of the north end of the county, which is far famed for its fishing grounds. In altitude Franklin County ranges from 355 feet on Androscoggin River near Chisholms Mills to 3,388 feet at the summit of Mount Abraham. The central part of the county is very mountainous, and contains few villages and few lines of transportation. The Maine Central Railroad extends as far as Farmington, through a fairly settled district, but the region north of Farmington is reached only by the Sandy River, Phillips and Rangeley, and Franklin and Megantic railroads, narrow-gage lines, which extend north as far as Carrabasset and northwest as far as Rangeley and several summer camps, the latter of which are reached by unimportant branches. Rangeley and Mooselookmeguntic lakes are also reached by the Portland and Rumford Falls Railway, which runs northward from Rumford Falls, in Oxford County, as far as Oquossoc, on the western edge of Franklin County. A map of this county showing the distribution of deep wells, important springs, and communities having public supplies forms Pl. XIII. This report considers only the region south of the forty-fifth parallel.



UNDERGROUND WATERS.

RELATION TO ROCKS AND SURFACE DEPOSITS.

Distribution of rock types.—The rock formations of Franklin County are not well known, but are supposed to consist almost entirely of granite and slate, with slate predominating. An area of granite enters the southwest corner and crosses the county in a northeast direction, the band having a width averaging less than 10 miles. This granite is quarried at Jay, on the Maine Central Railroad. It does not extend north of Dryden. A small granite area enters New Sharon from the east and heads for the area in which Jay is situated, indicating that these two areas may be connected at no great depth below the surface.

The known distribution of the rocks in this county can probably be best described by stating the areas in which they cross the several lines of transportation. North of the most northern outcrop at Dryden, on the Maine Central Railroad, the formation is entirely slate as far as Strong, on the Phillips and Rangeley Railroad. In the vicinity of Phillips, however, there is a patch of granite several miles across. Beyond Phillips no more granite is encountered until the railroad turns west, just north of East Madrid, in the mountain region. An area of granite is crossed here for about 10 miles, beyond which the rocks are slaty as far as Rangeley. Rangeley Lake is situated entirely within the slate area, but from this lake southward, along the Portland and Rumford Falls Railway, the formation is granite as far as Houghton, just beyond the borders of this county. On the Franklin and Megantic Railway the formation is supposed to be entirely slate from Strong—the junction of the Phillips and Rangeley and Sandy River railroads—northward as far as Carrabasset. Here, however, an area of granite is entered and continues to the end of the railroad at Bigelow. The village of Stratton, 7 miles northwest of Bigelow, is situated in the granite area. West of Stratton, however, the rocks are believed to be slaty in nature. In the extreme northern part of Franklin County, extending from a point near Beaverpond as far as the Canadian border and westward to the Oxford County line, is another area of granite. As a great part of Franklin County consists of wilderness, the detailed geology of this county is unknown.

Surface deposits.—In Franklin County the drift deposits are generally thick in the valleys and very thin in the hills. On Sandy River and some of the smaller streams there are extensive sand plains of unknown depth. In the vicinity of Farmington these are underlain at a few feet by clay, probably an extension of the same clay deposit which follows Kennebec River for so many miles. Irregular sand and gravel deposits are widespread over the county and are generally underlain by boulder clay, which also forms the surface over much of the uplands.

WELLS.

GENERAL DESCRIPTION.

Franklin County is so well provided with springs that wells are less numerous than in other parts of Maine. Dug wells are, however, common in the valleys, especially in the southeastern part of the county. The general depth of the dug wells is from 10 to 30 feet, though a few are more than 40 feet in depth. They are mostly sunk in drift, but a few wells have been blasted in rock. Most of the wells in this county give plentiful supplies of water, and, as the population is not large, few wells are contaminated. No drilled wells are known to have been sunk in the county.

DETAILED DESCRIPTION.

Farmington.—The town of Farmington, the county seat of Franklin County, is situated on a sand plain bordering Sandy River and high above it. It formerly had a public supply from an infiltration well situated 30 feet from the river. As this did not furnish sufficient water for the village, a portion of the supply was drawn from the river. Most of the inhabitants used this water until recently, and few people in the village have wells. The supply is now derived from Varnum Pond. On the outskirts of the village are situated many dug wells, one of which reaches a depth of 58 feet. This well is reported to pass through 10 or 15 feet of sand, underlain by clay, which extends to the bottom of the well. It contains about 50 feet of water the year round. That the clay underlying the sand is very irregular in elevation is shown by a road section southeast of town in which the clay rises sharply through a height of 15 feet or so and reaches the general level of the plain. Between Farmington and Farmington Falls attempts have been made to drive wells in the clay, but all trials have failed, owing to clogging of the screens by fine clay particles.

With the foregoing exception the wells at Farmington are mostly less than 25 feet in depth and few exceed 35 feet. They are dug in sand and gravel and generally rest on clay. The rock in the vicinity is a dense slate, striking northeast and southwest and having a vertical dip. Between Farmington and Strong the supplies are derived mostly from springs, as the hillsides are steep and spring water is generally easily obtainable.

SPRINGS.

General statement.—As Franklin County is very hilly, it has numerous springs, and it is not likely that there will ever be any serious lack of water except locally. Springs are used by many families in the country districts for domestic supply, and at least two villages use them for public supplies. Within the county are

at least three so-called mineral springs, one of which ships water regularly by railroad, and a second has done so in the past. These springs are as follows:

Carrabasset Mineral Spring, Carrabasset.

Knowlton Soda Spring, Strong.

Rangeley Mineral Spring, Rangeley.

Carrabasset Mineral Spring.—Carrabasset Spring, belonging to the Carrabasset Mineral Spring Water Company, of Boston, is situated on the bank of a small stream 10 feet above water level, on the Franklin and Megantic Railway, a short distance south of Carrabasset station. It issues near the base of a sand plain which rises only 10 feet higher at its central point, about 250 feet away. The spring was formed by digging a well 15 feet deep to a soft, shalelike rock. The water is reported to come from the rock. It is colorless, odorless, and tasteless, and has a temperature reported to be 46° in summer and 42° in winter. The flow is 5 gallons a minute after a storm and 2½ gallons a minute during a dry spell. It is said that after a heavy rain an hour or so elapses before the spring is affected. The water is used for drinking at a farm and two cottages situated near by and is bottled and shipped to Boston as a table and medicinal water. The price is 25 cents a gallon, or \$1 for a 5-gallon bottle. A part of the water is carbonated. The company runs a bottling establishment on the spot, and the spring is well protected by curbing on all sides. An analysis of the water, recalculated from that published in the company's circular, is reported in the table (No. 230).

Carrabasset Spring No. 2.—Not far from the Carrabasset Mineral Spring, on the opposite side of the river, is a spring, owned by the same company, which issues from the side of a high eskerlike ridge. The analysis of this water is given in the table (No. 231). No water is yet shipped.

Knowlton Soda Spring.—The mineral spring belonging to Mr. R. W. Knowlton is situated in South Strong, 7 miles north of Farmington. According to the owner, the spring emerges from a rocky hillside at the rate of 8 gallons a minute. It is reported by the owner to have valuable curative properties. The spring is covered by a three-story building, where the water is bottled. An analysis, recalculated from an analysis furnished by the owner, is given as No. 235 in the table.

Rangeley Mineral Spring.—The Rangeley Mineral Spring is owned by the Rangeley Lake Hotel Company, and is situated a short distance from the Rangeley Lake House, on a gentle bowlder-clay slope at least 50 feet above the highest part of the town of Rangeley and 60 feet or more below the crest of the hill. The

water seeps out of the hillside in a small stream. It has no color, odor, or taste and is very cold. As the spring house is always closed, the volume of flow could not be measured. The water is piped through a 1½-inch pipe to the Rangeley Lake House, where it is used for all drinking and cooking purposes. It has sometimes been shipped to Boston. No improvements have been made, with the exception of digging out the spring to a depth of about 8 feet, stoning it up with bowlders from the field, and building a small spring house over it. The water has been used since the hotel was started in 1896. It is probable that many other springs of good quality could be obtained on the same hillside. The analysis reported by the owners of the spring, recalculated into ions and parts per million, is given in the table (No. 234).

PUBLIC SUPPLIES.

General statement.—In Franklin County public water supplies are not common. Several towns, including Farmington, Phillips, Rangeley, Strong, and Kingfield, use water from surface sources. Farmington Falls has a supply from springs.

Farmington Falls.—The water system of Farmington Falls is a gravity supply from springs situated in sand and gravel hills near the town. These springs have been in use for about thirty years. No pumping is necessary, and the water is brought to town in a 1-inch pipe, which is lead except where it crosses the river, that portion being made of iron. The system is owned by the Farmington Falls Aqueduct Company, consisting of thirteen shareholders, who paid \$100 each at the time of its establishment. These persons and four other families use the water for domestic purposes, the four outside families paying \$8 a year each. The water is of excellent quality and never gives out, but in dry seasons it is occasionally rather low. A field assay resulted as shown in analysis No. 233 of the table.

Strong.—The Strong Water Company was installed in 1905 to supply the village. The wells in town had been satisfactory, but it was thought advisable to put in this supply for the sake of the additional conveniences. The water is taken from a small pond a few acres in extent situated on the slope of the mountain west-southwest of Strong. There are 75 faucets and 12 fire hydrants in the village, and seven-eighths of the people are said to use the public supply. The pond is reported to be 600 feet above the village. It gave at first a pressure of 200 pounds, but now it has been regulated to 80 pounds, which is sufficient. This water, from a high source on the mountain, is excellent in quality.

Rangeley.—Rangeley has a public water supply from Cascade Brook, on the flanks of Saddleback Mountain. The water is good; but, notwithstanding this fact, about half the inhabitants use dug

wells 10 to 30 feet in depth. The Rangeley Lake House has a fine supply piped to the hotel from a spring on the hill. Other springs could be obtained and used if desired, but the present public supply seems entirely satisfactory.

Kingfield.—Previous to 1898 the village of Kingfield used dug wells 10 to 25 feet in depth, and typhoid fever was prevalent. In that year a public supply was installed from Tufts Pond Brook, and the typhoid suddenly disappeared. The water is now excellent and few wells are used.

PREDICTIONS AND RECOMMENDATIONS.

The water supplies of Franklin County are so uniformly excellent that suggestions regarding their improvement may be considered unnecessary. Several villages, however, of which the largest is Rangeley, draw water largely from dug wells situated within their limits. In all such villages no time should be lost in installing a system of waterworks, either from some mountain brook of which the water is perfectly safe from pollution, or from springs, or drilled wells, or other safe wells. As yet no deep wells have been drilled in Franklin County. The reason is obvious—they have been unnecessary in most places. In towns like Rangeley and Farmington, however, which have not entirely satisfactory systems of waterworks, it would be possible to obtain water by drilling wells through the gravels and underlying clays into the bed rock, and such supplies would be safer for drinking than the ordinary dug wells situated within the town limits.

HANCOCK COUNTY.

GENERAL DESCRIPTION.

Hancock County lies in southeastern Maine, bordering on Penobscot, Bluehill, and Frenchman bays and including a large number of islands. Its western edge is formed by Penobscot River. This county is about 90 miles in extreme length from north to south, about 50 miles in greatest breadth, and has a total area of 1,390 square miles. According to the census of 1900 its population was 37,241. The largest city is Ellsworth, with 4,297 inhabitants, but Bar Harbor has a large summer population and is an important place during a few months of the year.

Hancock County can be said to consist of three sections—the island region and the adjacent inhabited region, which together comprise about one-half of the area, and the wild lands, which make up the other half. The wild lands are confined to the area lying north of the Maine Central and Washington County railroads, which cross the center of the county. The only other transportation line on land is a branch of the Maine Central Railroad which enters Bucksport, the

northwesternmost town in the county, from the north. The surface configuration of Hancock County is very diverse. Much of the coast is low and consists of gently sloping rock ledges or of clay or boulder-clay plains, but on Mount Desert Island many of the cliffs are precipitous, and there are mountains that rise to an extreme altitude of about 1,500 feet. Inland from the coast, especially in the region situated north of the railroads, there are many mountains, some of which reach elevations as high as 1,200 feet. Throughout the county are scattered numerous lakes and ponds. A map of this county showing distribution of deep wells, important springs, and communities having public supplies forms Pl. XIV.

The water conditions of Hancock County vary greatly. Away from the coast most of the wells are dug wells, which give fair supplies. On the coast and on many of the islands, however, water is harder to obtain and drilled wells are the rule, especially in the summer resorts.

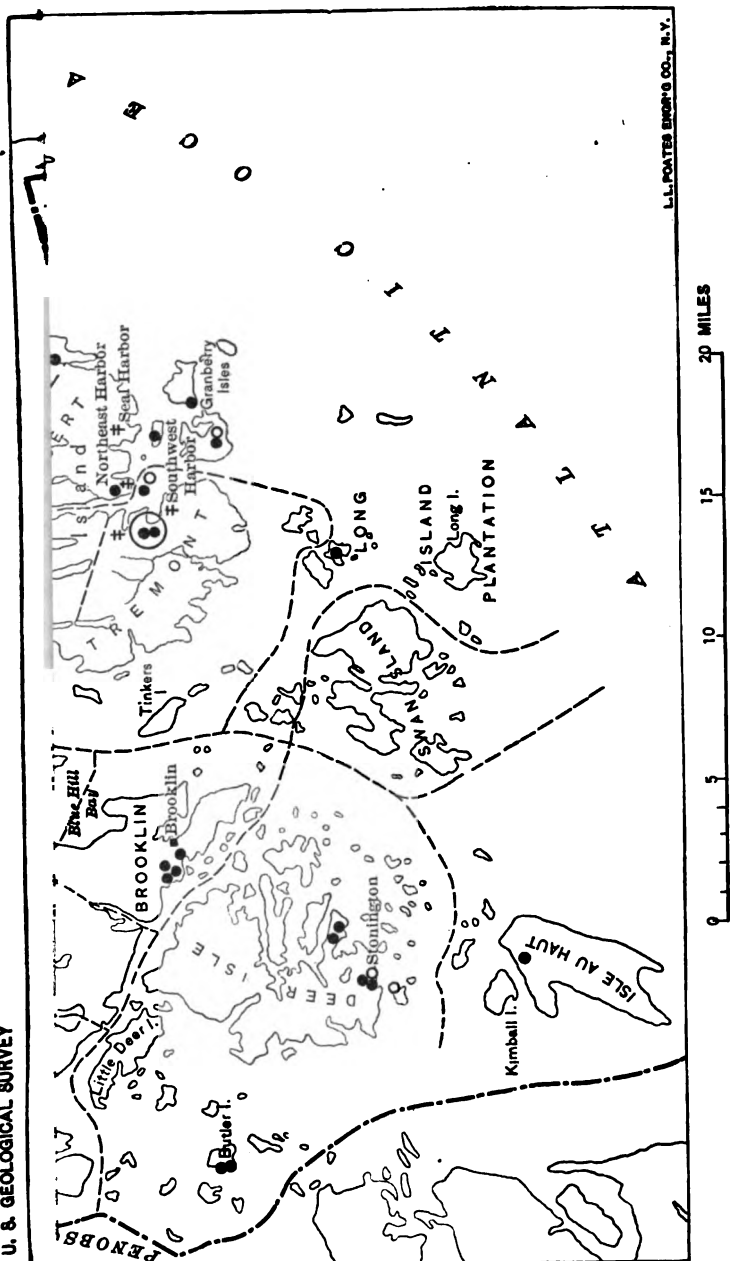
UNDERGROUND WATERS.

RELATION TO ROCKS AND SURFACE DEPOSITS.

Distribution of rock types.—The prevailing rock in Hancock County is granite, which, however, is irregularly distributed. It forms the greater part of the islands, although the northwestern part of Deer Isle, the coasts of Mount Desert, and many smaller islands are composed of other rocks. Castine, Brooksville, Sedgwick, and Penobscot are underlain in part by volcanic rocks. With the foregoing exceptions the area west of Ellsworth is granite. The towns of Ellsworth, Hancock, Lamoine, and Trenton, and a strip extending northward with an average breadth of 5 to 10 miles, supposedly as far as Amherst and Aurora, are underlain by slate and schist. Another small patch of slaty rock lies in Sorrento and the southern part of Sullivan and Township VII, in the southeast corner of the county. North of this area and covering the two eastern tiers of towns in the county an area of granite extends to an unknown distance, probably nearly to Great Pond. The north end of the county, within the area under consideration, is known to consist of slate, but north of the forty-fifth parallel lies another area of granite.

The structure of the granite of Hancock County is typical of Maine granite in general, as described on pages 29–32. The area mapped and described as granite in this part of Maine includes, however, small areas of diorite ("black granite") and similar rocks.

At Hall's quarry on Mount Desert, at Stonington, at Sullivan, and at Vinalhaven the granite is extensively quarried, and numerous exposures at these places show water seeping out of the sheet joints, as explained on page 31 and illustrated in Pl. III. At one place, near Stonington, a good spring issues from a vertical joint crack on



MAP OF HANCOCK COUNTY.

Showing distribution of deep wells, important springs, and communities having public water supplies.

the hillside. The direction of the joints is variable, but the majority of them trend between N. 75° E. and S. 50° E. Their size is small, but they seem to hold plenty of water in places.

The slate in Hancock County is extremely variable in character, at some places being hard and blue and at others consisting of a very metamorphic schist, much contorted and containing locally a large amount of iron and other minerals. In places, as at Bucksport, the slate becomes very hard, dense, and quartzitic.

The detailed distribution of the rocks in a small section of southern Hancock County has been worked out by G. O. Smith, E. S. Bastin, and C. W. Brown, of the United States Geological Survey, and hence it is possible to describe the formations of this region somewhat more fully than those of others. A considerable part of the area is granite, but the intervening regions are occupied by other igneous and stratified rocks distributed very irregularly. The distribution of the formations that have been mapped by the geologists in detail is described under the various townships.

Surface deposits.—The surface deposits of Hancock County are extremely variable in character and thickness. In Penobscot, Bluehill, and Frenchman bays the coast of the mainland and islands consists mostly of bare rock and the smaller islands are covered only with a thin coating of drift. In a few areas protected from wave action along the coast low clay plains are found, and in several places in Bluehill and vicinity low drumlin-like deposits of bowlder clay occur. On the larger islands and on the mainland away from the coast the drift is of considerable thickness. The bowlder clay is generally 5 to 50 feet or more thick, and in the valleys it is commonly overlain by sands, gravels, and clays. At Orland a cliff of bowlder clay rises 100 feet vertically above tide water of the river. In exceptional cases bowlder clay is underlain by sand, as in the well of Mr. Tom Mason, near East Orland.

WELLS.

GENERAL DESCRIPTION.

Types of wells used.—Certain parts of Hancock County are abundantly supplied with water from springs, but wells are generally more abundant on the coast and on the islands. Old-fashioned dug wells are common, and in many of the country districts are preferred by the inhabitants on account of the large amount of water contained in the drift. A few driven wells have been sunk through sand and clay in certain localities, and some of these have discovered small artesian supplies.

Drilled wells.—Along the coast and on the islands the most popular and best type is the drilled well, of which more than 170 have been

sunk to depths exceeding 50 feet. The prevailing size used is 6 inches and the depth varies from 30 to 675 feet. Most of the drilled wells in the county have been successful in obtaining fair amounts of potable water. A few have been failures owing to the absence of sufficient water or to the penetration of salt water into the wells. The failures have been commonly in schist and metamorphic rocks, seldom in granite. Where little water is found the difficulty is probably due to the fact that the wells did not chance to strike a fissure containing water. Another well near by might meet with success. As the greatest amount of water in the rocks is held comparatively near the surface, it is seldom advisable to drill below 200 feet or so. Instead, if a well reaches that depth without obtaining water, a second attempt should be made 50 to 100 feet away.

Quality of water.—The quality of water in Hancock County is extremely variable, owing largely to differences in the character of the formations. An example of the nature of waters which are generally obtained from deep wells in sand is shown in No. 184 of the table (p. 83), where the total solids are seen to be only 66 parts per million. Several dug wells in till have been tested by field assays in Orland, Eden, and Sorrento, and are low in mineral content. The amount of chlorine in some of these wells indicates possible pollution.

The wells in granite, of which four laboratory analyses have been made, give total solids from 81 to 364 parts, the lowest amount being found in a well on Greenings Island near Southwest Harbor, and the highest in the Crabtree & Havey well at North Sullivan. The chlorine in these four wells varies from 17 parts in a well at The Settlement, Stonington, to 140 parts in the Crabtree & Havey well. As these are deep drilled wells, not subject to pollution, the chlorine is probably a natural constituent of the rock. Sulphates range from a trace up to 25 parts per million, with one report of 104 parts. Carbonates run from 8 to 70 parts, and calcium, magnesium, sodium, and potassium are present in moderate amounts. In several analyses a little iron is reported, but this is not generally found in granite. The analyses of granite waters in Hancock County are tabulated on page 77, Nos. 9 to 19.

Three complete analyses have been made of waters in slate in Hancock County (Nos. 55, 56, and 57). One is from a 308-foot well in the village of Bucksport, the second is from an open well a few feet distant, and the third from a well in Hancock. The first two of these analyses show 116 and 53 parts per million of total solids, respectively. An interesting feature regarding these wells is that while the water of the deeper one is more than twice as high in total solids as that of the open well, the chlorine is the only constituent which is highest in the latter. This feature is strong evidence of pollution in the open well. Water from a slate well in the village of

Orland contains a little iron, and much iron is known to be contained in schists in some parts of the county. Near North Penobscot a well so situated is so strong in iron as to be almost useless.

Many wells along the coast have been ruined by the entrance of salt water from the sea. This occasionally happens in granite, but is much more common in slate. An example in the town of Sorrento is described on page 67.

Quantity of water.—Although it is unsafe to depend on the figures given by well drillers and owners as a guide to the amount of water likely to be furnished by a well, they are of some use as a general guide to the amount which may be expected. Wells in this county report all yields up to 100 gallons a minute, those commonly reported being only 3 to 5 gallons a minute, which, however, is plenty for all domestic purposes. A few wells gave too little water to be used. Most of the drilled wells hold out from year to year, when sunk deep enough, but dug wells often run dry. In a drought several years ago many of them gave out.

Uses.—The water of wells in Hancock County is used mainly for domestic supplies, and drilled wells are fairly common at summer cottages. In Castine, Southwest Harbor, Sorrento, and Stonington, however, they have been sunk for public supplies. At Sorrento a driven-well system has been abandoned for a surface supply, and the Stonington well was never used. At Hancock Point an abandoned mine shaft is used for public supply. At Brooklin a canning company has a drilled well; at Stonington granite quarries use them. The wells of Hancock County are commonly operated by hand pump, but many are rigged with windmills and a few are pumped by steam, gasoline, or hot air.

Flowing wells.—Several flowing rock wells are known in Hancock County. A number at Hancock flow from a bed of gravel confined underneath clay, and a similar local basin is situated near the village of Sorrento.

DETAILED DESCRIPTIONS.

Ellsworth.—As Ellsworth has a satisfactory public supply from a pond, very few wells are now in existence in the city. There are no drilled wells. The rock formation is slate and schist, and as drilled wells in these rocks are generally successful elsewhere it is probable that here too they would meet with success. At Ellsworth Falls water can be seen seeping out of joint cracks in slate, and this indicates the availability of water for wells in these rocks.

Bluehill.—The part of the town of Bluehill lying northeast of the village and extending nearly as far as North Bluehill, the region lying southwest of Bluehill Falls and extending eastward to South Pond, and a small section in the extreme northwest corner of the

town are underlain by granite. A strip just east of the granite area, in the western part of the town, consists of diorite, diabase, and gabbro. Long Island is made up of granite as far north as Deep Cove; otherwise this town, including the north end of Long Island, the whole of Bluehill Neck, the vicinity of Bluehill village, and North Bluehill, is composed of schist.

Several deep wells have been drilled in this town to supply summer cottages along the shore. Dr. A. M. Thomas has a well 140 feet in depth, in gneiss. Unfortunately the water is very turbid, owing to the entrance of clay through crevices in the rock. The supply is sufficient, as the water can not be lowered by pumping and yields 2,500 gallons in three or four hours per day, but on account of its quality it can be used only for the stable. The well belonging to Mrs. Ethelbert Nevin at Bluehill Falls is reported to yield $7\frac{1}{2}$ gallons of water a minute. On account of the great amount of iron contained in the rocks over large areas in the town of Bluehill, it is probable that some wells here will fail to get water. Analyses made of the two above-mentioned wells did not, however, show any iron. The amount of carbonates was high for Hancock County, being 92 and 110 parts per million, respectively. Where the rock consists of granite, gneiss, or hard, compact slate the water will generally be of good quality. In the vicinity of Bluehill village most of the wells are dug to ledge and some are blasted, getting good water. Bluehill Mineral Spring is situated in this town.

Sedgwick.—The town of Sedgwick is nearly all underlain by granite. In the southern part of the town, extending from Benjamin River westward along the coast to the Punchbowl, is a strip of volcanic rocks. Between the villages of Sedgwick and North Sedgwick stretches another strip, which consists of schists. In the vicinity of Bluff Head is a small area of schist, and between Bluff Head and the northern corner of the town lies a small area of diorite.

No drilled wells are known in Sedgwick. The dug wells are 8 to 20 feet in depth, and most of them get plenty of water in drift. A few run dry in summer. The water is commonly of good quality.

Brooklin.—The portions of Brooklin lying south of Brooklin village, and including the end of Flye Point and the islands of the town, are granite. North of Brooklin village the town is entirely underlain by schist.

Several deep wells have been drilled in the vicinity of the little settlement known as Haven. These are from 50 to 112 feet in depth and find plenty of water that is reported to be of good quality for domestic purposes. One of the wells here, owned by Noah V. Tibbits, is reported to supply 20 cottages. This well is 87 feet deep, and a number of veins of water were found. A drilled well of the Brooklin Packing Company supplies a sardine factory and near-by houses.

Castine.—The rocks of the peninsula of Castine are entirely volcanic, and consist mostly of a stratified variety known as tuff. The village of Castine is supplied with water chiefly from deep drilled wells, but in part by springs. Many people continue to use dug wells, which generally yield plenty of water, but which, being situated in the heart of the village, are clearly subject to contamination. The Castine Water Company has four wells, 58, 70, 80, and 110 feet deep, situated on one of the highest hilltops of the peninsula. On another hilltop a well 675 feet in depth was drilled by the same company. This is an 8-inch well and one of the deepest in Maine. The first water was found at 425 feet and rose within 25 feet of the well mouth. The well is reported to yield about 13 gallons a minute through the day, but is not very satisfactory on account of its poor construction. Further data regarding these wells are given under "Public supplies" (pp. 147-148). The fact that the last-mentioned well was sunk to a depth of 425 feet without striking water indicates that wells in this section will probably not all be successful. This statement is emphasized by the result of the well drilled for the Acadian Hotel Company on the hillside on which Castine is built. In July, 1906, this well was down 227 feet and the test with the hand pump showed a yield of only about 1 gallon of water a minute. As the owner did not consider the yield sufficient, he was advised to discontinue this well and start a new one a short distance away.

Bucksport.—At the Eastern Maine Conference Seminary, Bucksport, a well was drilled to a depth of 308 feet. Water was struck at about 100 feet and a second seam at about 300 feet. In the spring of the year when it was drilled water overflowed the surface, and the well supplied several gallons a day of excellent water. It is pumped by a 3-horsepower gasoline engine. Analyses of water from this well and from an open well a few feet distant are given in the table (Nos. 55 and 56). It is interesting to note that all the constituents are higher in the deep-well water than in that from the shallow well, with the exception of chlorine, which is higher in the open well. This indicates the probability of contamination in the open well. In another part of Bucksport two wells, 30 and 80 feet deep, were drilled only 3 feet apart, in quartzite, and connected by blasting. Only one of these is pumped. The supply is not large, but is sufficient for domestic purposes.

Orland.—In the town of Orland several drilled wells have been sunk, with varying results. The best well in town was that drilled for Mr. Tom Mason at East Orland. This well started on a gently sloping hillside consisting at the surface of boulder clay containing numerous large boulders. Instead of striking rock at a few feet, as might have been expected, the drill went through 87 feet of sand and gravel and then struck an excellent supply of water directly on

top of a bed of clay. The water is clear and cold, and 8 gallons a minute can be pumped. The well is very low in mineral matter, as shown by analysis No. 184 in the appended table.

A well drilled for Mrs. A. W. Hutchins, near North Penobscot, was not so successful. The rock is here a hard, traplike formation containing a considerable quantity of iron. This well was dug 12 feet in bowlder clay, blasted 8 feet through ledge, and then drilled 57 feet, making a total of 77 feet, striking water at 67 feet. The water tastes very strongly of iron. (See analysis No. 59.) It can not be used for washing because it stains everything with which it comes into contact, and iron is precipitated from the water when it is left standing for some time.

At the village of Orland three wells have been drilled to depths varying from 40 to 70 feet. One of these was abandoned because of the large amount of iron contained in solution and the supposed connection of the well with the river. A second well gives plenty of water, which has a slight iron taste, but not enough to interfere with domestic use of the water. The quantity of iron is not more than half a part per million, and the other minerals are low, as shown by a field assay (No. 58). That the water is highly prized is shown by the fact that eight families use it in seasons when the surrounding dug wells run low. The water is reported to be softer than when the well was first drilled, seventeen years ago. This well is situated on a point of rock which projects into the river and on which a number of cottages have been built. Across the river the formation is quite different, a steep bluff of bowlder clay being exposed for a height of about 100 feet. It is improbable that much water could be obtained from this material. Throughout the town of Orland dug wells are the prevailing type. They do not often give out, but frequently get very low. Where not polluted the water is of good quality. An example of the quality of water in till is given by a field assay (No. 170). The well from which this water was taken supplies six to eight families during a drought. Generally, however, water is not so abundant in till.

Stonington.—The wells of Deer Isle are all open wells except in the vicinity of Stonington, where a number of drilled wells have been sunk. At Stonington the sanitary conditions are very poor, only five wells having been drilled; the rest of the people use dug wells and springs, the water of which is polluted and dangerous. The town is thickly settled, is growing rapidly, and has no sewerage system. The formation is entirely granite, and hence the results obtained in drilling here have a rather important bearing on the occurrence of water in granite in general.

Two of the most successful wells in the region were drilled in 1906 at Mr. J. C. Rogers's quarry at "The Settlement" to supply water

for quarrying operations. The first well was 93 feet 8 inches in depth, passing through 27 distinct "beds" of rock. The thickest mass of rock uninterrupted by joints measured 14 feet, but some were only a few inches in thickness. The thickest bed was encountered about midway from top to bottom of the well. This well supplied 62 gallons of water in seven minutes, but the supply was not considered sufficient and a second well was drilled 50 feet distant. It was sunk to a depth of 279 feet and intercepted the same water-bearing fissures as those found in the first well, as was proved by the fact that pumping the second well lowered the water in the first. A week's test was made on these wells. They are said to connect 60 feet below the surface, and will yield 60 gallons a minute. A field assay of the water of the first well and a laboratory analysis of that of the second are given in the table (Nos. 18 and 19).

In the village of Stonington Mr. Samuel Goss has a well 67 feet in depth, also drilled in granite, which supplies his hotel. A field analysis of this has been made (No. 15). The Goss well supplies also fifteen or twenty families, and the water is used for watering lawns, etc. Ten years ago the Pine Lake Water Company sunk a well on the summit of Thurlow Hill, near the village, for the purpose of procuring a public supply for the village. The well was drilled to a depth of 183 feet, and is reported to have yielded 18 gallons of water a minute, but was plugged and has never been used. The Guyer & Torey well was drilled to a depth of 67 feet to supply two families, and a windmill and tank were installed and pipes run to the houses before it was discovered that the supply was too small to be used. The Sunset House, Acadian House, and a dozen residences are supplied by a good spring situated on a hill outside the village. The result of a field assay of this water is given in the table (No. 240).

In one quarry at Stonington the approximate amount of water issuing from the granite can be calculated from the amount pumped out of the quarry. The writer was informed by the foreman that more than 3,000 gallons accumulate daily in the bottom of the quarry from the joints. Near this quarry a good spring issues from a vertical joint which is said to be as wide as a common pencil. The crack is situated on the hillside below the quarry, but as it was covered it could not be seen.

One of the difficulties in quarrying granite on the smaller islands near Stonington is lack of water. On Moose Island there is a small catchment area consisting of a swamp, and water is obtained from a dug well near by. On Crotch Island the quarry of the Ryan-Parker Construction Company is 130 feet in depth, mostly below sea level, and is nearly dry. In a search for water another well was drilled to a depth of 300 feet, but without success, except that salt water was encountered. The chlorine in this well was 70 parts per

million and the sulphates 104 parts. (See analysis No. 17.) In 1907 a second attempt was being made for water on the opposite side of the island. No other drilled wells have been sunk in the vicinity of Stonington.

On Deer Isle there is a good chance of getting water at moderate depth. On the smaller islands, however, conditions are less favorable and as a rule drilling will probably not pay. In the vicinity of Stonington there is very little drift overlying the granite, and this circumstance probably explains why so little water is found by drilling on the smaller islands.

Deer Isle.—About half of Deer Isle, comprising the area lying east of a line drawn from Smalls Cove through Deer Isle village and Torry Pond to Eggmoggin Reach, consists of granite. This area also includes the islands lying in that part of the town. West of the above-described line the major portion of the island consists of acidic volcanic rocks. There are one or two small patches of schist in the northern part of the island and several areas of greenstone west of Deer Isle village. The wells on this island are dug in boulder clay and the depth of the deepest is 28 feet. The amount of water is extremely variable.

Little Deer Island consists of volcanic rocks and small areas of associated formations. The other islands of the town of Deer Isle in Penobscot Bay are made up almost entirely of volcanic rocks and greenstone. No drilled wells have been sunk. From the variability of the rocks a broad range may be expected in the character of the well waters.

Swans Island Plantation.—Swans Island consists entirely of granite. No drilled wells are known to have been sunk.

Long Island Plantation.—There are several islands in Long Island Plantation, but the only one on which a well is known to have been drilled is Black Island. This well was sunk to supply the granite quarries, but the water is also used for domestic purposes. The depth is 78 feet, and it is reported to be a good well.

Eden, Mount Desert Island.—Mount Desert Island consists of three towns—Tremont, Mount Desert, and Eden. Bar Harbor is situated in Eden, Northeast Harbor is situated in the town of Mount Desert, and Southwest Harbor is in Tremont. The coasts of the island are generally high and rocky and much wave worn. The water supply of Bar Harbor and Halls Cove is derived from Eagle Lake and is one of the best supplies in the State. At the fair grounds near Bar Harbor a well belonging to Gen. Edward Morrell obtained an abundant supply of pure water at a depth of $87\frac{1}{2}$ feet, in granite. A large number of cattle are watered every day, but the supply never gives out. A field assay of this water is reported in the table (No. 9). As Bar Harbor has one of the best lake supplies and filter galleries in the

State, there is little need for sinking wells in this village. A number of cottages at Schooner Head and vicinity have a supply brought in pipe from The Bowl, high up on Newport Mountain. Near Bar Harbor is a mineral spring known as Red Rock Spring.

At the village of Otter Creek, 5 miles south of Bar Harbor, two wells were drilled to depths of 25 and 37 feet, obtaining small amounts of water, in granite. If they had been sunk 50 to 100 feet deeper the supply might have been sufficient. The first of these wells was drilled to a depth of 25 feet, striking a vein sufficient in quantity for drinking but not for other purposes. An attempt to deepen the well was made by an inexperienced driller, who filled it with loose stones and afterwards lost the drill, and the hole had to be abandoned. A well dug in till in the southwestern part of the town gave the field analysis shown in No. 169. Many fine springs occur in this town.

Tremont, Mount Desert Island.—At Southwest Harbor two wells have been sunk by the Southwest Harbor Water Company. The first successful well was drilled in 1891 to a depth of 125 feet. The second well, 36 feet distant, was drilled in 1899 to a depth of 297 feet. These wells communicate at a depth of 90 feet. They could not be lowered by pumping, but enough water could not be obtained, owing to the insufficient capacity of the pumps in use and possibly also to the inadequacy of the supply, and Long Pond was resorted to as a supplementary supply. A full description of the waterworks is given on pages 148–149.

Many people in Southwest Harbor still use dug wells less than 30 feet in depth. The water is of variable quality. The field assay of a spring which issues from the clay along the shore near the village is given in the table (No. 241). This water flows 3 gallons a minute out of gravel beneath clay, and is highly prized by the owners. The spring is said to be sometimes covered by water at high tide. In the northern part of town is a historic spring, made famous by Indian legends, and the water is highly prized by the residents and visitors. The spring has never been improved. In the villages of Tremont, Bass Harbor, and McKinley only dug wells are used. It is probable that deep wells here would be successful.

Greenings Island, Tremont.—On Greenings Island a well was drilled in 1893 for Mr. J. G. Thorp to a depth of 88 feet, in granite. This well is located only 100 feet from high-tide mark and 20 feet above it. The supply is reported sufficient. The water is pumped to a 5,000-gallon tank for use in the house. (See analysis No. 10.) At the north end of the island the cottages are now supplied by pipes laid under the sound from Southwest Harbor.

Quite different in results from the above is a well drilled at the opposite end of the island about 1903 for Mr. Colton. It is 110 feet deep and salt water was encountered at a depth of 90 feet, where the drill

struck ledge. The water is so salty that it is not used. The drill stuck once or twice in crevices. The occurrence of salt water on this island is not confined to any particular part of the island, but is believed to be largely a matter of chance. A well near this one might be fresh, and, conversely, a well might happen to strike salt water at the north end of the island.

Town of Mount Desert.—Mr. L. E. Kimball, of Northeast Harbor, had a well drilled several years ago for the cottages there and the well was later bought by the water company. It was sunk to a depth of 189 feet. At 90 feet from the surface water commenced to enter the well. Several soft places in the ledge were encountered, and at one place the drill dropped as much as a foot. The water increased in volume with depth, and when the well was finished the test showed 60 gallons a minute for twelve hours, and it could not be pumped dry. The water is good, but somewhat irony. The well was abandoned when the public supply was installed. The rugged character of the town of Mount Desert makes springs very numerous. In the vicinity of Hall's quarry a number of good ones issue from the base of granite cliffs several feet in height. In that quarry considerable water can be seen issuing from sheet joints. At one time enough water for drinking was obtained near the bottom of the quarry.

Cranberry Isles.—On Sutton Island a well was sunk to a depth of 199 feet. This well will yield 20 gallons of water a minute and the water is of good quality. It supplies seven houses on the island.

On Great Cranberry Island a well was drilled in 1904 by Mr. Moorfield Storey to a depth of 201 feet, but it was abandoned, as only a very little water was found. In 1906 a second well was drilled, but the data regarding it have not been received.

On Little Cranberry Island a well 50 feet in depth was sunk for Miss Frothingham. The supply is reported to be 5 gallons a minute.

Hancock.—The village of Hancock is situated on a neck of land which is rather flat and low. A creek flows nearly across the neck and on the lowland lies an area of blue clay ("flat's mud"), below which is sand and gravel. In the square at Hancock, in 1904, a hole was bored with a 2-inch auger, and a strainer was attached to the bottom of the pipe. Below the soil was found a hard blue clay containing fossil shells; below this was a 6-inch bed of fine sand, underlain by coarse gravel containing excellent water, which flowed 9 feet above the surface of the ground. The water will still sometimes rise to a height of 5 feet, but the head is somewhat less than this in dry weather. A dug well near by is not quite so deep, but overflows the surface the year round. The town well averages half a gallon a minute. There are a few other good flowing wells in the vicinity, and most of them are bored. This area is a local artesian

basin, only a few hundred feet across, and the head of the water is caused by the inclination of the gravel bed, which holds the water underneath the clay. The gravel bed reaches the surface east of the wells and is inclined downward toward the west. The wells drilled into the clay but not through it are less satisfactory.

The deepest water supply in the town of Hancock is the village supply of Hancock Point. The source is an old shaft sunk about 1880 for a silver mine. It is 8 feet in diameter at the top and 98 feet in depth. The mine was unsuccessful and was abandoned, and later it filled with water within 4 feet of the surface. The water is said to be of fine quality for drinking purposes until the middle of August in every year, when it is reported to take on a brackish or mineral taste. The water is used only during the summer season.

In the vicinity of Hancock several wells have been drilled and reach depths of 30 to 70 feet. An analysis of the Jeremiah Stratton well, 65 feet in depth, is given in the table (No. 57). A few families use springs. Most of the wells in the vicinity are dug.

Many wells in North and South Hancock are reported to have run dry during the summer following the earthquake shock in March, 1903, while others which were then dry became filled with good water. In a few cases where wet and dry wells stood side by side the one containing water dried up and the other filled with water. Some wells that went dry are reported never to have recovered. Similar instances are reported in the town of Ellsworth. It is probable that the reports regarding these phenomena are correct, but it may be fairly questioned whether the cause was not a dry season rather than the light earthquake shock. The filling up of certain wells may be explained by the slow natural infiltration of water after they have been abandoned for some time.

The supply of the Maine Central Railroad at Mount Desert Ferry is from a spring 2 miles north of the village of Hancock. The Ishka Mineral Spring is situated in this town.

Sullivan.—The village of Sullivan, or Sullivan Harbor, has used water from Long Pond since the spring of 1905. It is good, clear water, but sometimes tastes of algæ. In the past most of the people have used wells or springs, but they are rapidly giving them up for the pond water, which is supposed to be of better quality. Open wells here obtain water in part from drift and in part from rock, and the supply is of variable quality and quantity. Mr. Dwight Braman has a 10-inch well drilled to a depth of 89 feet in granite. The water rises within 8 feet of the surface. It is used for drinking at the Manor House and is reported to have been sold. On the same estate is an abandoned silver-mine shaft, 120 feet deep and 20 by 15 feet in diameter, which is now full of water.

In the same village Capt. S. V. Bennis once had a well drilled 180 feet in depth. This well was 6 inches in diameter at the top and 5 inches at the bottom. The supply of water was small and the well has not been used for thirteen years. The owner reported that the well is drilled in slate which is very dense and contains a great many quartz veins. The Bennis well is situated less than 1,000 feet from the Braman well, and the smaller amount of water encountered in the former may be due in part to the fact that the slate in this locality, as is often the case near granite areas, is very dense, containing few joints, and holds little water, whereas the granite, in which the Braman well was drilled, contains a great many water-bearing joints.

In the vicinity of West Sullivan several shafts of abandoned mines have been transformed into wells. One at West Sullivan was drilled 40 feet and obtained good water, but on continuing it to 61½ feet water which is too highly charged with mineral matter to be used was obtained and the well was abandoned. The surface wells in this vicinity, however, give good supplies of soft water. The public supply of West Sullivan comes from a spring.

At North Sullivan the conditions seem to be much better. The formation is of granite, and a number of wells 50 feet in depth obtained plentiful supplies of as good water as can be found in the State. Some of these wells have been blasted in rock; others were drilled. A comparison of the two types of wells here indicates that for shallow wells in granite the cost of both is about the same, but for deep wells the drilled type is cheaper. For both shallow and deep wells the drilled type is safer.

One of the best wells is that of Mr. C. H. Abbott. This well, after going through 3 feet of drift, struck granite and went to a depth of 136½ feet without obtaining water. On drilling 10 inches deeper a seam of water was struck and a two-hour test was made; in that time 2,000 two-gallon pailfuls were pumped and the water was lowered only 11 inches. In the construction of the well hard galvanized-iron tubing was put down to rock, driven as hard as possible, and cemented to the ledge. With this construction it is impossible for surface water to pollute the well. The assay of this water is given in the table (No. 11). This granite water is a delightful-tasting, clear, cold water. Complete analyses of the Crabtree & Havey well (No. 14) and of the John M. Blaisdell well (No. 13) are given in the table. In the Crabtree & Havey well the amount of mineral matter is very high, being 364 parts per million. A view of the Crabtree & Havey well is given in Pl. V, B.

Sorrento.—The summer resort of Sorrento, situated on a peninsula at the southwest end of the town of Sullivan, has a gravity water supply from Long Pond, taking the water from the end of the pond oppo-

site to that from which it is taken by Sullivan. Sorrento formerly had 14 driven wells, installed a dozen years ago, consisting of 2-inch pipes sunk from 50 to 65 feet in depth in gravel deposits a mile north-east of Sorrento. They are reported to have been nearly all flowing wells. They were situated in a low, swampy area a few hundred feet in extent, bordered on the north and south by rock hills and on the east by hills of gravelly till, and a small brook drained out to sea at the west end. Small gravel hills surround the valley, giving a head to the water, which is confined in quicksand below a bed of clay. The wells stretched along an east-west line and were 100 feet or so apart, ranging as much as 50 feet on either side of the center line.

At Sorrento two wells, 92 and 61 feet deep, were drilled in rock about fifteen years ago. Both gave salty water, but one of them was used for a short time. In the rock along the shore are a number of cracks as much as one-half inch in diameter which might allow passage for water into the hill and downward into the wells. The dip is toward the south, and it is probable that the salt water enters the cracks parallel with the stratification of the rock on the north side of the peninsula. Drilled wells are not recommended on this smaller peninsula, but on the major peninsula which juts out from Sullivan they may meet with success. A dug well in till in the northern part of the major peninsula was tested by field assay (No. 171).

Penobscot.—The rocks of the town of Penobscot are also very diverse in character. In the vicinity of South Penobscot, extending northward beyond Wight Pond and southward as far as North Brooksville, the formation is granite, as it also is north of Pierce Pond. Between Pierce Pond and the village of Penobscot, and along a narrow strip just east of Wight Pond, is a band of diorite which encircles the South Penobscot granite area. East of Wight Pond, with the exception of the narrow strip of diorite, the rocks are schist as far as the Bluehill line. West of Northern Bay and south of Wallamatogus Mountain the rocks are volcanic. As in Deer Isle, great difference may be expected in the character and amount of well waters.

Surry.—A strip of granite of variable width extends along the southwestern edge of Surry, but with this exception the region southwest of the village is made up of schist. No drilled wells are known. It is probable, however, that in both the granite and the schist areas drilling will be successful.

SPRINGS.

General statement.—Away from the coast Hancock County is well provided with springs, many of them supplying farmhouses, and some are pumped by windmills. At Greens Pond, in the town of

Dedham, a spring supplies the hatchery and nursery of the United States Fish Commission, and the spring water is piped through the buildings. Within the limits of the county there are at least four important mineral springs, as follows:

Bluehill Mineral Spring, Bluehill.

Ishka Spring, West Hancock.

Katagudos Spring, Eastbrook.

Mount Desert Spring, Bar Harbor.

Bluehill Mineral Spring.—Two springs owned by Greely & Hagarthy, of Ellsworth, are situated in a valley about 3 miles north of Bluehill post-office. The water is reported to issue from a ferruginous rock with a volume of 5 gallons a minute. It is colorless and odorless, but contains some sediment. It is highly charged with iron and other minerals and has deposited iron about its mouth. The analyses reported by the owners and recomputed into ions and parts per million are given in the table (Nos. 236 and 237). The total amounts of solids in the two springs are reported as 79 and 49 parts per million. The water is used for medicinal purposes. The existence of this spring was noticed by Jackson as early as 1838.^a

Ishka Spring.—The Ishka spring is situated near a hilltop 4 miles north of the village of Hancock. The total solids are reported as 19 parts per million (analysis No. 242). The spring is covered with a house and the water is bottled for shipment.

Katagudos Spring.—The spring known as the Katagudos is situated in the town of Eastbrook, 8 miles northeast of Franklin post-office. The water is said to seep out of a hillside formed of surface deposits, with a volume estimated by the owner as about 8 gallons a minute. The water is said to be colorless and odorless and to have a pleasant taste. It is used for drinking and medicinal purposes and a small hotel is situated there. The owner is Mr. R. B. Lowrie. The analysis of this water is reported in the appended table (No. 238), the composition being recalculated from the analysis reported by the owner.

Mount Desert Spring.—Mount Desert Spring water comes from a spring owned by Messrs. J. H. Souris and C. A. Waters. The water is said by the owners to issue from a fissure in granite. The flow is reported to vary slightly, but to average 12 gallons a minute. Much water is sold in the vicinity and some is shipped to a distance. An analysis, reported by the owners and recalculated from the original into ions and parts per million, is given in the table (No. 239). The water is reported to have medicinal value. The price is 12 cents a gallon.

^a Jackson, Charles J., Report on the geology of the State of Maine, 1838.

PUBLIC SUPPLIES.

General statement.—In Hancock County very few villages have public supplies. The following, however, use surface water: Bucksport, Northeast Harbor, Ellsworth, Sullivan, and Sorrento. One town in the county, Castine, gets its water from wells and springs, and Southwest Harbor gets it from wells and a pond. Lamoine has a supply from springs, and Hancock Point uses an abandoned mine shaft. A deep well was sunk at Stonington some years ago for a public supply, but it was never used.

Castine.—The village of Castine is supplied by two private water systems. The larger of these is owned by Mr. A. M. Deveraux, who has several deep drilled wells situated on the summits of the hills occupying the center of the peninsula. In addition to the wells a number of springs are used.

The first well was put down by a driller who promised water at a depth of 60 feet. The well was drilled 57 feet 8 inches, and the tools stuck, making it necessary to abandon the hole. It was filled with stones to prevent any other driller from making use of it, and a second hole was drilled 2 feet away. This one went 62½ feet, got a good supply of water, and continued 3 feet deeper for a reservoir. A third hole, 12½ feet distant, was drilled to a depth of 70 feet. By pumping the two successful wells it was found that they communicated and that it was only necessary to put a pump in one of them. The water level stands 25 feet from the surface. Another well was drilled 10 feet away from No. 3, to a depth of 80 feet, water being found at the same depth, 62½ feet, and rising to the same level as in the others, 25 feet from the surface. Later, hole No. 2 was deepened to 110 feet.

On another hilltop a well 675 feet in depth was drilled for the same water company. This is an 8-inch well and is one of the deepest in Maine. The first water was found at 425 feet, and filled the well within 27 feet of the surface. The cost was \$3,500, and much trouble was caused by losing the drill, obtaining a crooked hole, etc., due to inexperienced drilling. The well is reported to yield about 13 gallons of water a minute through the day, but is not very satisfactory on account of its poor construction.

The three principal wells belonging to this system are now pumped by a windmill into a cement-lined tank situated on the hilltop near by. The maximum capacity of the three wells is reported to be about 27 gallons a minute. The capacity of the tank is more than 25,000 gallons, but the supply from the wells is seldom sufficient to fill it. The other well belonging to the system is situated about a mile from these and is also pumped by a windmill into a tank having a capacity of more than 30,000 gallons. The supply from this well also is insufficient, and the tank is never full.

As a temporary supply, to make up the deficiency of water in the wells, the owner has installed a system of springs. These are situated on low land in the eastern part of the peninsula, in sand and gravel. A system of tiling several hundred feet in length was put in, extending 6 to 10 feet from the surface downward into the clay on which the sand rests. This system catches the water held in the sand by the impervious clay below and is reported to give 10,000 to 20,000 gallons of water a day. The water is pumped by steam to a reservoir or tank near by, and thence to a reservoir on the hill near the deepest well.

Mr. Deveraux reports that 150 water takers are on his system. This includes two hotels, one of which recently put down a drilled well for the purpose of obtaining its own supply. Unfortunately this well was a failure. With the wells and springs constituting the public supply there seems to be plenty of water to meet the demand for it. The spring system, however, is reported to be only temporary, and the owner contemplates installing a system of driven wells instead. Mr. Deveraux's company is sometimes known as the Castine Water Company.

The other company in Castine is known as the Castine Aqueduct Company. The water is taken from springs in gravel, and is used by a few persons. A number of people in the village prefer the use of dug wells, as of old. Many of these wells are in poor locations and unsafe. They should be abandoned.

The price charged for water in Castine by the Castine Water Company has recently been raised from \$7.50 to \$10 a year. On account of this increase many people have given up the public supply and are depending on the dug wells. The price charged by the Castine Aqueduct Company to its patrons in the lower part of the town is \$6 a faucet.

Southwest Harbor.—The village of Southwest Harbor has a water supply taken from two sources, both owned by the Southwest Harbor Water Company. Until recently most of the water was taken from two drilled wells situated on the summit of the hill just west of the village. These wells and the conditions of water in them are described on page 141. The first well used was 136 feet deep and pumped 45 gallons a minute. The second, 20 or 30 feet from it, was sunk to a depth of 297 feet. The windmill was first situated over the old well, and an 8-horsepower gasoline engine was also established to pump both wells. As both the windmill and the engine were insufficient to pump the two wells to their fullest capacity, a secondary water supply was installed from Long Pond. Another well, 125 feet deep, was never used.

The water from the wells and pond is pumped to a standpipe 225 feet above tide, the capacity of which is 107,000 gallons, and it can

be pumped full in seven hours of continuous pumping by means of a windmill. The pressure is reported to be 90 pounds on the main street. The length of pipe connecting the village of Southwest Harbor with Long Pond is about $2\frac{1}{2}$ miles. In addition to this the company has 1 mile of pipe extending to the steamboat landing and probably half a mile in the village. All these pipes are underground. The mains extending to Long Pond are 2 inches in diameter and the rest are one-half inch. Surface pipes extend to the village of Manset and to a great many cottages in the vicinity of Southwest Harbor. A 1-inch pipe runs below the sound to Greenings Island. Five fire hydrants are reported in the village of Southwest Harbor, but there are none in the outlying villages.

The majority of the people in Southwest Harbor use the water supplied by the company. A few, however, use dug wells. There are estimated to be 150 consumers, over 50 of whom, however, are summer residents. The rates are \$10 a faucet in private houses and \$7 in stores. During the winter all inhabitants except those on the lines which are buried use well and spring waters. The chief reason given for having so much pipe above ground is that ledge at many places lies close to the surface and to lay pipe in it would be very expensive. The water has been analyzed and is considered of excellent quality. The amount of sickness in town seems to have decreased since the waterworks were installed.

Lamoine.—Twenty families in the village of Lamoine are supplied by the Cold Spring Water Company. The water seeps out of sand deposits, and is pumped by windmill into a reservoir.

PREDICTIONS AND RECOMMENDATIONS.

Most of the towns in Hancock County seem to appreciate the value of pure water supplies. Stonington, however, while growing rapidly, has as yet no such supply. The people of this town use dug wells and springs almost entirely, and many of these are in situations where they are sure to be polluted from surface drainage. There are no sewers in the town, and altogether conditions are insanitary. It seems important that the dug wells and springs should be abandoned as rapidly as possible and a public water supply installed. This might be obtained from any one of several sources, among which are Burntland Pond and other ponds on the south end of the island. If none of these supplies are satisfactory it seems probable that a number of wells drilled in granite at a safe distance outside the village, away from the shore, would furnish plenty of water. There is always an uncertainty whether rock wells will obtain sufficient water for a village, however, and a pond supply should be obtained if practicable. There is plenty of water in the granite of Deer Isle for ordinary domestic purposes, and even for

small manufacturing and other establishments. Individuals or companies that can afford to do so will be wise to sink wells for drinking water.

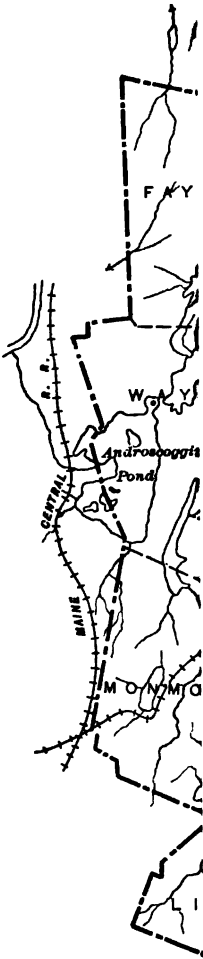
In most of the summer-resort districts of the county, especially on the islands, drilled wells are rather commonly used. Although some have been failures, there have been, on the other hand, a surprising number of successful wells drilled on islands where it would seem that the supply of water in the rocks must be small. In most localities the best method of obtaining water for cottages is by drilled wells. These should not go to a depth of more than 200 feet, as deeper drilling is generally of little avail.

A number of wells situated near the coast, and especially on the small islands, have been unsuccessful, owing to the entrance of sea water, which has ruined the wells. In certain wells fresh water has first been encountered, and by continued drilling to obtain a greater supply salt water has been struck; in others salt water has been struck first, the fresh-water seams existing at greater depths. Sometimes the water of the well is fresh, but by long-continued pumping becomes salt. In any of these cases, where both salt and fresh water veins are struck, it is possible for experienced drillers, by proper manipulation, as described on page 67, to close off the salt water and redeem the well.

KENNEBEC COUNTY.

GENERAL DESCRIPTION.

Kennebec County lies in the south-central part of Maine, on both sides of Kennebec River and directly east of Androscoggin and Franklin counties. It has a length from northeast to southwest of 50 miles and a maximum breadth from east to west of 35 miles. Its area is 880 square miles, and its population according to the census of 1900 was 59,117. The chief cities are Augusta—the state capital—with 12,379 inhabitants; Waterville, with 10,899; and Gardiner, with 5,501. The county is well provided with railroads, being crossed by a line of the Maine Central Railroad along Kennebec River and another line 5 to 15 miles west of the river, meeting the river line at Waterville. From Waterville the railroad runs northeastward to Burnham, and a branch extends north as far as Skowhegan, in Somerset County. The Somerset Railroad extends from its terminus at Oakland northward to Moosehead Lake, in Somerset and Piscataquis counties. A narrow-gage railroad—the Wiscasset, Waterville and Farmington—runs southeastward from Winslow to Wiscasset, in Lincoln County, and a branch of this railroad runs from Weeks Mills to Albion. The surface of Kennebec County is rather hilly, but is not so much so as some of the other counties in the State. The elevation ranges from sea level along Kennebec



River to more than 700 feet on some of the hills. The tide on Kennebec River penetrates as far inland as Augusta. Within the county are a great many lakes, which are mostly utilized for summer resorts. The largest body of water in the county is Great Pond, in Rome and Belgrade. Throughout the county the open well is the prevailing type, but some drilling has been done. A map of this county showing distribution of deep wells, important springs, and communities having public supplies forms Pl. XV.

UNDERGROUND WATERS.

RELATION TO ROCKS AND SURFACE DEPOSITS.

Distribution of rock types.—A large part of the county is underlain by slate. There is, however, a small patch of granite, about 5 miles in breadth, lying in the common corner of Manchester, Hallowell, and Augusta, and most of the area south of Gardiner consists of a complex of slate, schist, and gneiss, which can not be separated on any map.

Structural relation of the rocks.—Throughout nearly the entire county the slate strikes very uniformly northeast, and the dip of the strata and that of the cleavage are nearly vertical. The rock ranges from very shaly, or even fissile, to hard and dense, and in some places it is schistose.

Surface deposits.—The surface deposits of Kennebec County differ greatly in character and thickness. Along Kennebec River and up many of the side valleys there is considerable clay, which rises to elevations of more than 200 feet. In places this clay is underlain by gravels from a few inches to 50 feet or more in thickness. Elsewhere the clay is overlain by sand. On the hills the deposits are mostly till from 1 to 50 feet in thickness. In places, however, rather extensive morainal deposits are found on the hills, as in the vicinity of Augusta.

WELLS.

GENERAL DESCRIPTION.

Types of wells used.—The most common type of well in Kennebec County is the old-fashioned open well. These wells range in depth from 5 to 50 feet, and are dug in gravel or boulder clay. They are generally successful, but often run dry in summer. The water is generally of good quality except where the wells are so situated as to become polluted.

Drilled wells.—About 35 drilled wells have been sunk in the county, ranging in depth from 30 to 560 feet, the most common depth being about 100 feet. The wells are mostly 6 inches in diameter, but three or more 8-inch wells have been sunk. In general the shallower

of the deep wells have been successful, but a greater number of water veins and consequent larger supplies are obtained by going 100 to 200 feet. It happens that the largest supply reported was obtained from a well which went down more than 300 feet. This well got 50 gallons a minute at that depth. It seems worth the expense to drill as deep as this if sufficient water is not obtained nearer the surface. The deeper supplies in the slate have not been prospected, for the reason that plenty of water is obtained at shallower depths, but it would be well to drill a few test wells when more water is needed.

Quality of water.—Where unpolluted the well waters of Kennebec County are mostly good. The total solids as reported in four analyses range from 170 to 258 parts per million, but the amount of lime is never great enough to cause serious trouble in boilers. The only two complete analyses of slate waters in this county are given in the appended table (Nos. 62 and 67), but a number of field assays and other tests have been made (Nos. 60 to 70). Analyses 243 to 254 give the composition of several commercial spring waters.

DETAILED DESCRIPTIONS.

Augusta.—The city of Augusta is supplied with plenty of water of good quality from Cobbosseecontee Pond, and there is little necessity of using well water. One well 560 feet in depth, belonging to Mr. G. P. Sanborn, has been used for supplying a greenhouse. The amount of water is not large, and the well overflowed in rainy weather, indicating that the water may come from a surface source. Wells drilled in the neighboring town of Winthrop indicate that plenty of water may also be expected in the slate areas of Augusta, and wells drilled in granite at numerous places in Hancock, Lincoln, and Washington counties indicate that water may be expected in the granite areas in this city as well.

Hallowell.—Like Augusta, Hallowell has a surface water supply and is little in need of drilled wells. The only well known to have been drilled in the village is reported to have been sunk at Johnson Brothers' shoe factory. A well was drilled in 1880 on the farm of Mr. H. G. Vaughan to a depth of 70 feet, and enough water for drinking and farm purposes was obtained.

Farmingdale.—In the town of Farmingdale a number of wells have been drilled to depths of 50 to 110 feet. The water is generally of good quality, and there is plenty for ordinary domestic purposes. Assays have been made of two well waters in this town (Nos. 60 and 61).

Gardiner.—The water supply of Gardiner is taken from Cobbosseecontee Stream, just below the bridge at the upper end of the village of Gardiner. The water is reported good, but on account of the large number of farms situated along the banks of Cobbosseecontee Stream

and its tributaries and the proximity of the pumping station to the village the supply must be considered as of questionable safety for the future.

Formerly, dug wells were abundant in the village, but they are now nearly all abandoned for the city water. Some dug wells penetrate the clay and get plenty of water which never gives out and which is cold and has an excellent taste. One 20-foot well goes through clay and gravel and rests on ledge. This well is in the heart of the city and so situated that the water probably enters the gravel bed within the limits of the populated district, yet nine families use the water. A number of similar wells were seen, some of which use chain pumps. On account of the extreme danger of pollution of dug wells situated in a thickly populated village these can not be considered safe. They are probably even more dangerous than the river water. The bed of gravel underlying the clay seems irregular in thickness, in some places reaching 15 feet and in others being entirely missing. A few wells only have given out. The solution of the water problem at Gardiner seems to lie in the abandonment of the present system and the installation of a supply from a point higher up on Cobbosseecontee Stream or its tributaries, where the water is safe.

Gardiner is situated entirely in the area of the complex consisting of alternating slate, schist, gneiss, and granite. Little well drilling has been done; but in the southern part of the town there are two drilled wells, 34 and 36 feet in depth, which are interesting as showing what should and what should not be done in the location of wells. Mr. Joseph Douglas has a well drilled to the depth of 36 feet entirely in rock. A deep-well hand pump was installed with the intention of using the water for drinking. The well stands only 15 feet from the barnyard, however, and the water is colored brown and has a bad odor, indicating the existence of open cracks in the rock extending under the barnyard, and consequent pollution of the well water. A dug well 15 feet in depth on the opposite side of the road and in a safe location is used for drinking water.

As a contrast, an example of a well-kept well is that of Mr. Charles Hopkins in the same part of the town. This well is 34 feet deep, and was drilled fifteen years ago, striking schist at 5 feet from the surface. The well is pumped by a windmill and gives an abundant supply of water. By looking down the well with a hand glass after pumping it as nearly dry as possible the water can be seen issuing from a crevice as large as a man's hand. This well has obtained more water than was found by farmers in the vicinity who have blasted in rock. The blasted wells here cost much more than Mr. Hopkins's well, and thus furnish an argument in favor of the drilled type.

Waterville.—The city of Waterville, together with other towns of the Kennebec water district, obtains its supply from China Lake.

Formerly it was obtained from Messalonskee Stream, which was badly polluted and caused a great deal of typhoid fever. At present, however, there is little need of drilled wells in the city, as the China Lake water is satisfactory. It is possible that drilled wells may have been sunk in the town, but inquiry during the investigation disclosed none. If rock water supplies are desired, they can probably be obtained by drilling at nearly any point, as few unsuccessful wells have been drilled in neighboring towns.

Winslow.—In 1899 the Hollingsworth & Whitney Company had a series of seven wells drilled 60 feet from the bank of Kennebec River and 20 feet above water level. The wells are 110 to 125 feet deep and extend along a line 90 feet in length. The water was used for cooling acid in the manufacture of paper. The wells were pumped by compressed air, thereby obtaining 200 to 300 per cent of the amount obtained by an ordinary steam pump. Now, after seven years, the wells are said to have filled with sand until they are only about 90 feet in depth. While they were used, pumping one of them would lower the rest. They are now abandoned because of insufficient supply for the purpose desired, and river water is used instead. A 67-foot well belonging to the same company is still used to supply drinking water.

On the terrace above these wells a number of persons have drilled wells to depths of 30 to 65 feet. These have met with varying degrees of success, some of them having plenty of water, while others give out in dry weather. It is probable that they would be more successful if drilled to 100 feet or deeper, as a greater number of water veins would be tapped. On the terrace between Kennebec and Sebasticook rivers there are flat areas of considerable clay which are worked in places for the manufacture of brick. In places the clay is overlain by sand, and at the village of Winslow a spring issues from the sand on top of the clay and is piped to four houses for domestic use.

A rather interesting well is that of Mr. Will Glidden, which is 30 feet in depth, drilled in slate. The water rises from the slate by artesian pressure into a dug well, from which it is pumped by a wind-mill. The pressure of water here is derived from a 15-foot rise in the hill 400 feet back from the well. A number of wells in Winslow have been blasted in rock. The water from one well on a hill is siphoned to a house on the hillside below. Field assays have been made of water from three wells in this town (Nos. 64-66).

Chelsea.—No drilled wells are known in Chelsea, but some wells have been driven and some bored to depths of 20 or 30 feet. The dug wells are generally of similar depths and the water is almost always of good quality. It usually issues from sand. Many farms in the town and the Maine Insane Hospital obtain supplies from springs.

Oakland.—Oakland has a public supply from Lake Messalonskee. This lake does not seem to be entirely safe from pollution, but the water is considered of very good quality. Drilled wells are unknown in the town.

Pittston.—In Pittston several drilled wells have been sunk, which range in depth from 56 to 135 feet. The water seems to be good, and is used for domestic and farm purposes. The yield is 8 to 10 gallons a minute.

Winthrop.—Winthrop is the only town in Kennebec County where drilled wells have been sunk extensively, and the almost unfailing success here is an index of the supplies which may be expected to be found by drilling elsewhere in the county. No fewer than a dozen successful wells have been drilled, mostly pumping 12 to 50 gallons of water a minute.

The principal wells in the village of Winthrop are owned by C. M. Bailey Sons & Co., H. P. Hood & Son, and Charles H. Gale. The public supply of the village comes from a spring belonging to the Winthrop Aqueduct Company, from springs and drilled wells belonging to Charles H. Gale, and from springs belonging to Levi Jones. The principal water system is that of Mr. Gale, whose wells and springs are situated on the hill directly west of the village. The wells are three in number, and are 90, 96, and 65 feet deep. They give a fair amount of good water and can not easily be pumped dry. Probably half the people of the town use this supply. These wells and the associated springs are described in detail under the heading "Public supplies" (pp. 157, 158).

The best well in Winthrop was drilled in 1906 for C. M. Bailey, Sons & Co. at their factory. This was sunk to a depth of 307½ feet. At 300 feet from the surface a supply of fine water was struck, which when tested yielded 50 gallons a minute. The pump is generally run three hours a day, but has been run eight hours continuously without exhausting the supply. The water is used for boilers, but is also excellent for drinking. The analysis is given in the table (No. 67). The well of H. P. Hood & Son was drilled in 1903 to a depth of 172 feet. It was cased with 8-inch casing to ledge, a distance of 18 feet, and 6-inch pipe was then run down to 140 feet. It is reported to yield 25 gallons of water a minute and can not be pumped dry. In these two wells the water stands about 8 feet from the surface.

At Winthrop the rock is slate; at Baileyville (Winthrop Center) it is schist, but the water seems to be just as abundant. The well of Mrs. Hannah J. Bailey, drilled 200 feet through rock, obtained 15 gallons of fine water a minute and now supplies four families and a boarding house. The water is piped to the houses from a windmill. Messrs. C. I. Bailey and J. Briggs own a well together, and the depth and quality of the water were similar to those of Mrs. Bailey's well.

The yield is reported as 30 gallons a minute. All the wells at Baileyville have been successful, and the water is of good quality and has no iron taste. The marked success of wells in this vicinity is a strong indication that similar wells can be obtained in other parts of the slate area of Kennebec County.

Other towns.—In the towns of Litchfield, Albion, and Sidney there are scattering drilled wells. In the following towns no drilled wells are known to have ever been sunk, and the supplies are obtained entirely, so far as known, from open wells: Vienna, Rome, Mount Vernon, Fayette, Belgrade, Readfield, Monmouth, West Gardiner, Manchester, Oakland, Waterville, Clinton, Benton, Unity Plantation, China, Windsor, Chelsea, and Randolph.

SPRINGS.

General statement.—Springs are very common on the hillsides of Kennebec County. They usually issue from boulder clay or sand and at many places are used for domestic and farm supplies. In Augusta the Maine Insane Hospital draws its supplies from a spring situated back in the hills. At the village of Winthrop several small aqueduct systems take their water from springs situated on the hills west of the village. These are described under the heading "Public supplies" (pp. 157, 158). Within the limits of the county are the Forest Springs, at Litchfield; Pure Water Spring, in Waterville; and Ticonic Mineral Spring, at Winslow.

Forest Springs.—The Forest Springs Water Company was organized in 1900 for the purpose of marketing the water which comes from the Forest Springs, in the town of Litchfield, $1\frac{1}{2}$ miles northeast of Litchfield Plains. The springs have been renowned for their purity for more than a hundred years and are said to have been much frequented by the aborigines.

There are three springs. The first is 450 feet from the second and about a quarter of a mile from the third. The two principal springs are situated at the base of a gentle sandy slope, not far from a small brook; the third spring is farther back in the woods. The principal spring is in reality a well 6 feet in depth. At this place were encountered the following strata, from the surface downward:

<i>Section of drift at Forest Spring.</i>		Fect.
Gravel loam.....	.....	2
Clay.....	.....	1
Fine gravel.....	.....	28
		31

The spring was curbed down 6 feet and has a sandy bottom. It is situated in the woods far from any house, and the water is of excellent quality, with no chance of pollution. The analyses of the three

springs, reported in a circular issued by the company, are given in the table (Nos. 247 to 249), recalculated according to the standard method. The company has built an up-to-date bottling plant near the springs, and the water is carefully bottled and shipped in half-gallon and quart bottles and 5-gallon carboys. The flow of the principal spring is 100 gallons an hour.

Pure Water Spring.—The Pure Water Spring is situated $1\frac{1}{2}$ miles north of Waterville. The water is carbonated and sold in Waterville. The hardness is given by the owners as 41.5 parts per million.

Ticonic Mineral Spring.—About 2 miles northeast of Waterville is the Ticonic Mineral Spring, the product of which is sold in Waterville. The flow is reported as $5\frac{1}{2}$ gallons a minute. The analysis of this water is given in the table (No. 253), recalculated from the figures reported by the owners.

PUBLIC SUPPLIES.

General statement.—Eleven villages in Kennebec County—Augusta, Hallowell, Farmingdale, Gardiner, Randolph, Oakland, Waterville, Benton, Belgrade, North Vasselboro, and Winslow—have public supplies drawn from surface sources. The only important underground-water supply is that of Winthrop, which uses wells and springs. Hallowell, Augusta, and Vienna are reported, however, to have small spring supplies.

Winthrop.—The village of Winthrop has no regular municipal supply. There are, however, a number of aqueduct companies, and these furnish water to a majority of the population. Most of the water is supplied by Charles H. Gale, the Winthrop Aqueduct Company, and Levi Jones. The largest system is that owned by Mr. Gale, which consists of wells and springs situated on the hillside just west of the village. The wells are about 100 feet above the village and are sunk to depths ranging from 65 to 120 feet. The springs are near by, in a swampy depression in the hillsides. The water is collected in a reservoir.

At first consideration the swampy source of the springs would seem to be an argument against the use of this water. It can be said, however, that there may be no great danger of this water being contaminated by surface drainage. One house is situated on the hillside above, but it is so far away as probably to have no effect on the water supply. From the reservoir the water is piped to the town in galvanized-iron pipes, which are badly rusted by the water. As the system is a gravity system the water has a good pressure. There are reported to be about 150 patrons of the system, and this probably represents about half the village population. The wells are pumped by windmills. The owner reports that when the wells are used there is plenty of water to supply all needs. Without the

wells, however, the amount is not sufficient. No analyses of the water have been made except a sanitary analysis made some years ago.

An interesting feature was brought out in connection with this analysis. The water was sent to a chemist by a resident of the town, as it was supposed to be polluted. At the same time a sample taken from a dug well in the village was sent—a well extensively used by the residents and believed to be excellent. On receipt of the returns it was found that the water of the dug well was badly polluted and that the public supply was of excellent quality. This is a strong argument against the use of dug wells in a thickly settled village and in favor of the installation of deep-well supplies wherever practicable. There is some question in this case about the use of the springs. They are certainly not as good as the drilled wells, but they are probably safe.

The other water systems have their source in springs situated on surrounding hillsides, but the number of takers is smaller. The supply belonging to Levi Jones issues from a boulder-clay hillside and is conveyed by gravity in galvanized-iron pipes to the village. About 35 families are reported to use the water, which is believed to be of good quality.

The water rates in Winthrop are \$6 a year. The fire hydrants are supplied from an entirely separate source, pumped by the Winthrop Mill Company from another well.

Vienna.—A few persons, probably fewer than a dozen, in Vienna village are supplied by water from a large spring piped through a main three-fourths of a mile in length.

Hallowell.—In the town of Hallowell there is a supply owned by the city, reported to be derived from springs on Winthrop Hill. The water is obtained by direct pressure, and the pressure is 40 to 110 pounds. About 120,000 gallons are consumed daily.

PREDICTIONS AND RECOMMENDATIONS.

In Kennebec County few failures in well drilling have been recorded. The underlying rock of the county consists almost entirely of slate, and the almost uniform success of wells in rock of this type is contrasted to the frequent failures of wells in some other regions. So far as known, the public water supplies are at present all of good quality, although in the past there has been some trouble from water taken from Messalonskee Stream in the vicinity of Waterville. This supply is no longer used. No public supplies are known to be of poor quality. In Oakland and Gardiner, however, it would seem that the supplies are only temporarily safe; they are so situated that they may in time become polluted unless proper precautions are taken. Drilled wells in these towns would be a safeguard in case the condition of the water should cause trouble.

KNOX COUNTY.**GENERAL DESCRIPTION.**

Knox County occupies a nearly central position on the Maine coast. Its length from north to south, including the outer islands, is 35 miles, and its breadth is about 20 miles. It has an area of 327 square miles, being, with the exception of Sagadahoc, the smallest county in Maine. Its population, according to the census of 1900, was 30,406. Rockland, the chief city, contained 8,150 persons, Camden had 2,825, and Thomaston 2,688. The only railroads in the county are a branch of the Maine Central which crosses from Warren to Rockland, and the Georges Valley Railroad, a short line running from Warren to Union. The surface of the county is gently undulating in the southern part, but rather mountainous in the northern part. The altitude ranges from sea level to more than 1,450 feet, the highest elevation being in the town of Camden; and its surface is covered with a considerable number of ponds and small lakes. A map of Knox County showing the distribution of deep wells, important springs, and communities having public supplies forms Pl. XVI.

UNDERGROUND WATERS.**RELATION TO ROCKS AND SURFACE DEPOSITS.**

Distribution of rock types.—The rocks of Knox County consist largely of a complex of granite, diorite, slate, schist, etc. In the southeastern part of the county, extending from Rockport southwestward across Rockland, Thomaston, and Warren, are small bands of limestone rock, from a few hundred feet to about a mile in breadth, bordered by slates, schists, and quartzites. The limestone strata are much contorted, the rock is very hard, white to blue and gray in color, and is extensively quarried. In the eastern part of South Thomaston and St. George and covering the adjacent islands is a small granite area. The continuation of this area covers the greater part of Vinalhaven. A small area in the northern part of the same island and the entire island of North Haven consist of trap, slates, and acidic volcanic rocks.

The detailed geology of considerable portions of the county has been worked out by E. S. Bastin, of the United States Geological Survey, and will be given later under the names of the various towns.

Surface deposits.—The surface deposits of Knox County are irregular in thickness. Along the coast and in the lowlands the sands and clays locally run up to 100 feet in thickness, though usually much thinner, and their upper surfaces form flat plains near the coast and in the larger valleys. In the vicinity of Thomaston the clays are rather extensive. In some parts of the county there are small morainic deposits, which are in places as much as 100 feet thick, consist-

ing of sand, gravel, and till. Over the greater part of the uplands the surface is bowlder clay, ranging from 1 to 10 feet in thickness. In places this is absent and the hills consist of bare rock. Most of the water from dug wells in Knox County is derived from the surface deposits.

WELLS.

GENERAL DESCRIPTION.

Types of wells used.—The wells of Knox County are mostly dug wells, but on the coast and islands a considerable number of drilled wells have been sunk. The dug wells range from 5 to 30 feet in depth and are mostly sunk in bowlder clay or gravel. They contain plenty of water in the wet season, but in summer they often run dry.

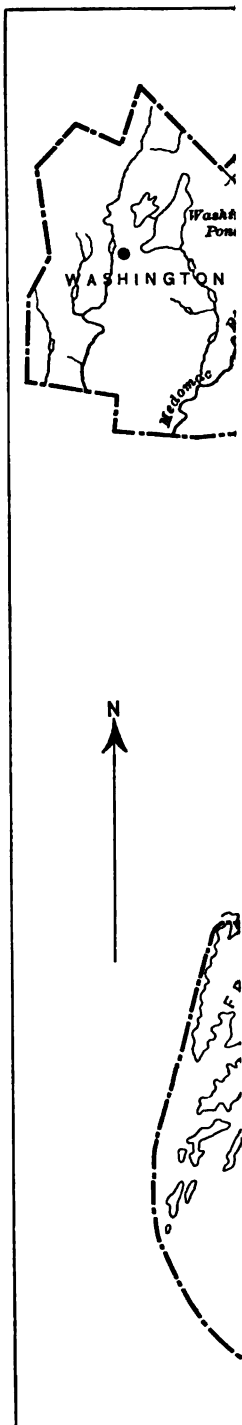
Drilled wells.—The drilled wells in this county are about 40 in number. They are from 50 to 640 feet in depth, and the yield ranges up to 25 gallons a minute. Most of the wells in the county have been successful, but several have failed. At North Haven a 300-foot well was dry, while a 200-foot well near it contained a small quantity of water. In the vicinity of Rockland one well was abandoned because the water was not sufficient to supply a large hotel, and a second well was salty. The county contains one flowing well which supplies the town of Warren. The wells between 100 and 200 feet in depth obtain the largest amount of water. Of the seven wells sunk below 200 feet, only one got an appreciable increase in the supply. These rocks probably do not contain much water below that depth.

Quality of water.—The quality of water in the wells of Knox County ranges from very soft to very hard, the hardness being dependent on the amount of lime in the rocks in which the wells are sunk. The only analysis of water from solid limestone is that of a sample from the bottom of one of the Rockland limestone quarries (No. 255). It will be noticed that neither the total solids nor the calcium is as high as in some waters from rocks that do not contain as much lime. The magnesium, however, is very high—22 parts per million.

The only other complete analyses of Knox County waters are those made from two trap wells at North Haven. The total solids in these wells are 90 and 2,057 parts per million. The excessive amount in the latter well is due to an admixture of sea water.

DETAILED DESCRIPTIONS.

Rockland.—The Rockland region is occupied largely by slate, schist, and limestone with minor areas of quartzite. In the north-west corner of the town the slates are broken up and are intruded by granites, gneisses, and similar rocks. West of the city proper is a narrow belt of crystalline limestone extending in an easterly direction from Thomaston toward Chickawaukie Pond. It is bordered



Showing

on the southeast by a number of smaller limestone bands. This limestone is extensively quarried, some of the quarries being several hundred feet deep. Those which are abandoned are filled with water. Associated with this limestone are a few narrow bands of quartzite.

Few dug wells remain in Rockland, but along the limestone region are a number which are dug to rock, striking it at depths of 15 to 20 feet. The water here is uniformly hard. There is plenty of it in winter, but it gives out in summer. In dug wells in the immediate vicinity of the quarries the water gave out, owing to the drainage of the surface deposits by the quarrying operations.

The limestone quarries in the vicinity of Rockland, Thomaston, and Warren are the only quarries in this kind of rock in Maine, and as they throw some light on the occurrence of water in limestone, they deserve special consideration. In Rockland several quarries extend to a depth of more than 300 feet below the surface. Some of them are now abandoned and filled with water within a few feet of the surface. Where they are being worked water can be seen entering from the joint cracks below a depth of about 80 feet from the surface. An example of the amount of water entering these quarries per day is furnished by a quarry 300 feet long, 70 feet wide, and 180 feet deep. In the bottom of this quarry is a hole 25 by 30 feet across and 4 feet deep which fills in about twelve hours during the night. This is at the rate of about 10 gallons a minute. The water is pumped out in about an hour and a half in the morning. It can be seen dripping into the quarry along the joint cracks, and in one or two places springs of considerable size are found. The most water enters along the ends of the quarries parallel with the stratification of the rock, but much of it comes in on the horizontal joints.

A number of quarries show caves in limestone, due to the solution of this rock by the water. One or two caves of considerable size were found. (See Pl. VII, B.) The largest are 5 feet across and extend more than 5 feet inward from the side of the quarry. In one place where the drift has been stripped from the surface a former water channel about 2 feet in diameter was seen running downward into the rock. A few solution channels are seen following the horizontal joints, and in places these are 2 to 4 inches in diameter. The occurrence of water in solution channels in limestone is a common feature in such rocks throughout the country, and the drillers frequently find that the drill drops several feet when a vein of water is struck. There is plenty of water in this rock at Rockland, but it is very hard.

The city of Rockland has an excellent supply of water from Oyster River Pond, with Chickawaukie Pond as an auxiliary supply. Not more than three wells are known to have been drilled in Rockland, and these have been abandoned. One was drilled on Crockett Point

in 1900 to a depth of 22 feet, striking rock at 3 feet from the surface, but was abandoned because the water was salty. In 1906 an 8-inch well was drilled at Hotel Samoset, Rockland Breakwater. The surface was clay rising a few feet above tide, but rock was struck at 14 feet and the well was sunk to a depth of 640 feet. At 185 feet 10 to 12 gallons of water a minute was struck, but below that no water was found. This supply was not sufficient for a large hotel and the well was plugged. However, the water would have been enough for several private families. No information can be obtained regarding the other well at Rockland.

Thomaston.—Northwest of a line drawn from the western edge of Thomaston village to Mount Battux in Rockland the rocks of this town consist of slate and schist. There is also a small area of slate crossing the village of Thomaston. The most conspicuous rock east of the slate area is a band of limestone, more than a mile in breadth, extending from the southern border of the town northeastward to Chickawaukie Pond, in Rockland. South of this limestone area are a number of alternating bands of quartzite, schist, and limestone which are too complicated for description. In a limestone quarry is a spring which is reported to give a good flow of water. As in Rockland, the dug wells overlying the limestone are from 10 to 20 feet in depth, and the water is very hard. Some of the wells rest on ledge. They sometimes run dry in summer.

Only one drilled well has been sunk in the town—that of the Thomaston Brick Company. It was drilled 46 feet through marine clay, then in limestone for 340 feet, making a total depth of 386 feet. The water is hard and the supply is only about 3 to 5 gallons a minute.

South Thomaston.—The eastern and southern parts of South Thomaston are composed mostly of granite and much associated gneiss and basic rocks. Between Weskeag River and Rockland Harbor is a band of slate and schist more than half a mile broad. West of this band the area consists of the same succession of quartzite, limestone, and slate which is found in the southeast corner of Thomaston. Most of the wells in this town are dug. At Crescent Beach a well was drilled in 1906 for Mr. F. M. Smith to supply cottages at that place. The depth was 75 feet, and the well furnished 5 or 6 gallons of water a minute, which was reported to rise within 2 or 3 feet of the surface in the wet season. The well can be pumped down 30 or 40 feet, but can not be exhausted. Other data regarding it are given in the section on "Public supplies" (p. 167).

Several wells are reported to have been drilled at Owlshead and Hendrickson Point, but information regarding them has not been received.

St. George.—The town of St. George consists almost entirely of granite. There are, however, in the western half of the town con-

siderable areas of diorite. The wells of this town are for the most part dug wells, but on Harts Neck, south of Tenants Harbor, at least three drilled wells have been sunk to supply summer cottages. Those of Mr. William S. Richardson and Mr. J. B. Aldrich are rather interesting. While these wells are situated so near the houses that windmills could not be built over them, the windmills were built a few feet distant and the wells are pumped by means of a connecting rotating horizontal rod. The wells are drilled 67 and 54 feet deep, in a very hard gneissic rock. The Richardson well is reported to yield only 2 gallons of water a minute. Another well near by was also successful. At Port Clyde a well is reported to have been drilled, but no information regarding it is at hand.

Warren.—The town of Warren is almost entirely underlain by granites, gneisses, diorites, and schists, mixed in the form of a complex. There are, however, small areas of other rocks. One of these extends as a narrow strip from the southern border of the town in the vicinity of Thomaston northward along the Thomaston and Rockland line beyond the head of Oyster River. Northwest of Warren village is a small area of limestone which is quarried. Most houses in the village of Warren have dug wells, but these are abandoned and the people use the public supply. This comes from a deep drilled well situated on the high hill east of the village. It is 196 feet deep and is reported to flow 5 feet above the surface without pumping. The volume is reported to be 8 gallons a minute, and in a test the well pumped 100 gallons a minute for five days continuously. The country rock is complex, and as no rock shows within half a mile it can not be said certainly from what material the water comes. For full information regarding this system of waterworks see page 166.

Rockport.—The entire western part of Rockport, including all the area lying west of the village of West Rockport, is occupied by a complex of granite, gneiss, diorite, schist, and other rocks. The area east of this line is composed almost entirely of schist, with some slate. There are, however, a few small areas—one in the vicinity of Oakland Park, a second just south of Rockport village, a third crossing the village itself, and a fourth between Rockport village and Simonton Corners—which consist of quartzite, and smaller areas in the village of Rockport and north of Simonton Corners consist of limestone. Rockport draws its water from Oyster River Pond, and hence wells might be considered unnecessary in the village. As the rock is near the surface, however, and it is hard to pipe the streets, many dug wells are still used. They should be abandoned as rapidly as practicable. Through the country the wells are mostly dug. One drilled well of moderate depth and fair success has been sunk for Mr. Oscar Gould near West Rockport.

North Haven.—North Haven and the outlying islands included within the town are composed principally of basic lavas or greenstone. A small area in the vicinity of North Haven village, however, stretching eastward across Stimpson, Babbage, Calderwood, and Burnt islands and Indian Point, is formed of volcanic rock. On the main island of North Haven considerable drilling has been done, especially near North Haven village. Messrs. C. S. Staples and J. M. Howe put down two wells in 1902 to depths of 200 and 300 feet. The deeper well was dry and the other obtained only $1\frac{1}{2}$ quarts of water a minute at 68 feet. Eighteen pounds of dynamite were exploded at that depth and the supply of water increased to 3 quarts a minute, but no more than this could be obtained. In 1893 Mr. Nelson Mullin had a well drilled 121 feet in trap in the same village. The water is called a little irony, but the supply is 5 gallons a minute and is considered satisfactory for a hotel and five cottages which are supplied from it. (See field assay, analysis No. 132.) Mr. F. S. Mead also drilled in trap and obtained 10 gallons a minute. The well belonging to Mr. F. H. Smith is 118 feet deep and supplies a store, three dwellings, a fish market, and a livery stable.

On the point a mile east of the village Dr. C. G. Wells had three wells drilled in 1891, 1895, and 1903 to depths of 122, 142, and 282 feet, getting 2, 20, and 6 gallons of water a minute, respectively. The water is found at various depths, is pumped by windmills and a hot-air engine, and is used for supplying cottages and a steam yacht. A short distance north of the wells belonging to Doctor Wells is one belonging to Mr. William A. Gaston, 57 feet in depth. One well at North Haven was ruined by the accidental admission of calcium carbide into it from an acetylene-gas generator. Analyses of two wells drilled in trap at North Haven are given in the table (Nos. 155 and 156). One of these was salty.

Vinalhaven.—The major portion of Vinalhaven is composed of granite. In the vicinity of Barley Hill and Coombs Hill and at several places near Vinalhaven village there are small areas of diorite. Zeke Point is made up of lava, but the northern half of Calderwood Neck is schist. The part of the island northwest of Seal Cove and Long Cove is largely lava, but a number of patches of diorite lie along the coast, and there are several small areas of schist and lava.

On the main island of Vinalhaven six or more wells have been drilled to depths ranging from 120 to 225 feet. Four of them are situated at the village of Vinalhaven, where sometimes as much as 20 gallons of water a minute is obtained from granite. The well of the Bodwell Granite Company, 125 feet in depth, is pumped by a gasoline engine and the water is used in dressing granite. Some veins of salt water were encountered below a depth of 50 feet in this well. The well of the Vinalhaven Fish Company, 225 feet in depth, is

pumped in the same way, gives 20 gallons of water a minute, and is used to supply a canning factory.

At the north end of the island the rock is mostly trap. There are a number of wells here, and these are from 100 to 200 feet in depth, obtaining from 10 to 25 gallons of water a minute by windmills. The well of Mr. J. M. Howe here supplies four cottages, and that of Rev. G. A. Strong supplies three cottages. (See field assay, analysis No. 133.) Mr. Howe owns several wells on the island.

The conditions observed in the granite quarries at Vinalhaven are as follows: No seepage of water from the joints was noticed, but they are somewhat stained by iron. One east-west joint, due largely to weathering, is 4 inches wide. Both systems of joints are well developed in places. In some parts of the quarries they are only 1 to 4 feet apart, but elsewhere they may be 10 or 20 feet apart. Near the bottom of a neighboring quarry four small seepages were seen from horizontal joint cracks. All the water obtained from these cracks is used for engines in the quarry and polishing house.

On Widow Island a 109-foot well drilled in granite for the Maine Insane Hospital yields 2 gallons of water a minute. The well is pumped by a gasoline engine and the water is used for domestic purposes by 70 persons. It is considered of excellent quality.

Camden.—About half the town of Camden, including the entire area lying west of a line drawn from Melvin Heights northeast to the Waldo County line, is composed of a complex of granite, gneiss, diorite, and schist. The region east of this line is occupied by slate and schist, with the exception of an area extending from the extreme west end of the village of Camden northeastward to the saddle between Mount Battie and Mount Megunticook, which is composed of quartzite, and of a small patch south of the village and extending into Rockport which is composed of limestone. There are also a few small patches of quartzite, limestone, and other rocks scattered promiscuously through the town.

Camden has a good surface water supply from Mirror Lake, and the village is not in need of wells. On its borders and in the country districts people still use dug wells, which give water of variable quality. No drilled wells are known to have been sunk.

Other towns.—In the towns of Washington, Hope, Union, Friendship, and Cushing no drilled wells are known. The conditions are as usual in the country districts and supplies can be obtained by dug wells, but these are of variable quality and sometimes run dry in the summer.

SPRINGS.

Knox County is well provided with springs. In the town of Camden Mr. Frank Alexander has a spring consisting of a well-like hole, 2 feet in depth, dug in the bottom of the cellar, 6 feet below the sur-

face of the ground. The material is hard "pin gravel." Mr. Alexander has a waste pipe 2 feet below the cellar and the spring overflows to a near-by valley. This spring was installed before the town had a public supply. It is described here as an example, for the reason that spring waters coming from under dwelling houses are not safe. When springs have their origin in sands and gravels at a distance from houses they are generally preferable, but they can not be recommended when they are so situated as to be influenced by surface drainage from surrounding buildings.

PUBLIC SUPPLIES.

General statement.—The towns of Rockland, Camden, Rockport, and Thomaston have an excellent public water supply furnished by the Camden and Rockland Water Company and drawn from Mirror Lake, in the town of Camden. Two communities in this county—Warren and Crescent Beach—use deep wells for their public supplies, and two villages—Union and Friendship—have spring supplies.

Warren.—The village of Warren is supplied by the Warren Water Company, which has an artesian well situated on the hillside about one-half mile east of the village. The well is 196 feet in depth and is a drilled well 6 inches in diameter. It was sunk 54 feet in 1900 and to its present depth in 1903. The flow began at 165 feet and increased to 185 feet. The well is reported to flow 5 feet above the surface without pumping and to give a volume of 12 to 15 gallons a minute, but is fitted with a windmill and a gasoline engine for use when necessary. When tested for five days and five nights it averaged 100 gallons a minute. The hill on which the well is situated consists of a gentle boulder-clay slope rising toward the east, and the well is about 100 feet above the highest part of the village. The water is pumped to a reservoir situated some 800 feet distant. It is in the midst of pasture land, but is surrounded by a barbed-wire fence 10 feet from the nearest point of the reservoir. The pressure is 85 pounds. An 8-inch main carries the water to 10 fire hydrants and most of the residences in town.

This water company is said to have been formerly conducted by Mr. White, who had a shallower well on the same site as the present one. On account of failure the present company was formed. The well seems to give a plentiful supply of water, as evinced by one occasion when there was a fire and two lines of hose were run to the burning building without the water being exhausted. The rate is \$7 a year for family use for one faucet, but an extra charge is made for other faucets. The water is said to be of excellent quality. The principal constituents shown by a field assay are given in analysis No. 134.

Crescent Beach.—Crescent Beach, in the town of South Thomaston, is supplied by a drilled well belonging to Mr. F. M. Smith. The well is situated on a gentle gneissic slope at some distance from the village. It is 75 feet deep and was guaranteed by the drillers to give 6 gallons a minute. It is pumped by a windmill which has been run steadily a week at a time. Sometimes a gasoline engine is used. The water can not be pumped out, but can be lowered 30 feet. When not pumped it often stands only 2 feet below the surface. The water has been considered good by the users, but sometimes gives a bad odor. An examination of the well disclosed the probable cause. The casing is open at the surface, thus giving a chance for mice, snakes, or other small animals to fall in. This is a good example of how a well should not be kept. The top of the casing should always be closed. The well has supplied about 25 cottages at the beach, also the stable and hotel buildings.

Union.—The village of Union is supplied by the Union Water Company through a gravity system from springs on the hillside east of the village. There are two springs, reported to flow 2 gallons a minute each, which seep out of bowlder clay. About 80 families are said to use this water. The pressure is 50 to 80 pounds.

Friendship.—The village of Friendship is supplied by a spring system owned by the Friendship Water Company, of Warren. The water boils up through sand at a reported rate of 20 gallons a minute. It is pumped into a tank by a windmill. It is good soft water and seems to be entirely satisfactory for domestic use. The system is said to supply 60 families.

PREDICTIONS AND RECOMMENDATIONS.

The public water supplies of the larger villages of Knox County are all of good quality, so far as known, and there seems to be little necessity for their improvement. In view of the fact that most wells drilled within the county have been successful, it is suggested that drilled wells be used more extensively. They will be found especially satisfactory on the islands and rocky coasts of summer resorts, where it is difficult to get an adequate supply from open wells.

LINCOLN COUNTY.

GENERAL DESCRIPTION.

Lincoln County lies a little southwest of the center of the Maine coast. It is 40 miles in length from north to south and 20 miles from east to west. Its area is 520 square miles, and its population in 1900 was 19,669. Wiscasset, the county seat and largest town, contained only 1,273 inhabitants. About 7 miles of the western border of the county fronts on Kennebec River. The county is crossed by the

Maine Central Railroad from Wiscasset to Waldoboro and by the Wiscasset, Waterville and Farmington Railroad, a narrow-gage line running north from Wiscasset to Winslow in Kennebec County. The surface of the county is much broken up by indentations from the sea projecting many miles inland, and the coast is lined by a great many islands. The altitude ranges from sea level up to about 500 feet on a few of the hills. Along the coast considerable well drilling has been done. The distribution of deep wells, important springs, and communities having public supplies is shown in Pl. XVII.

UNDERGROUND WATERS.

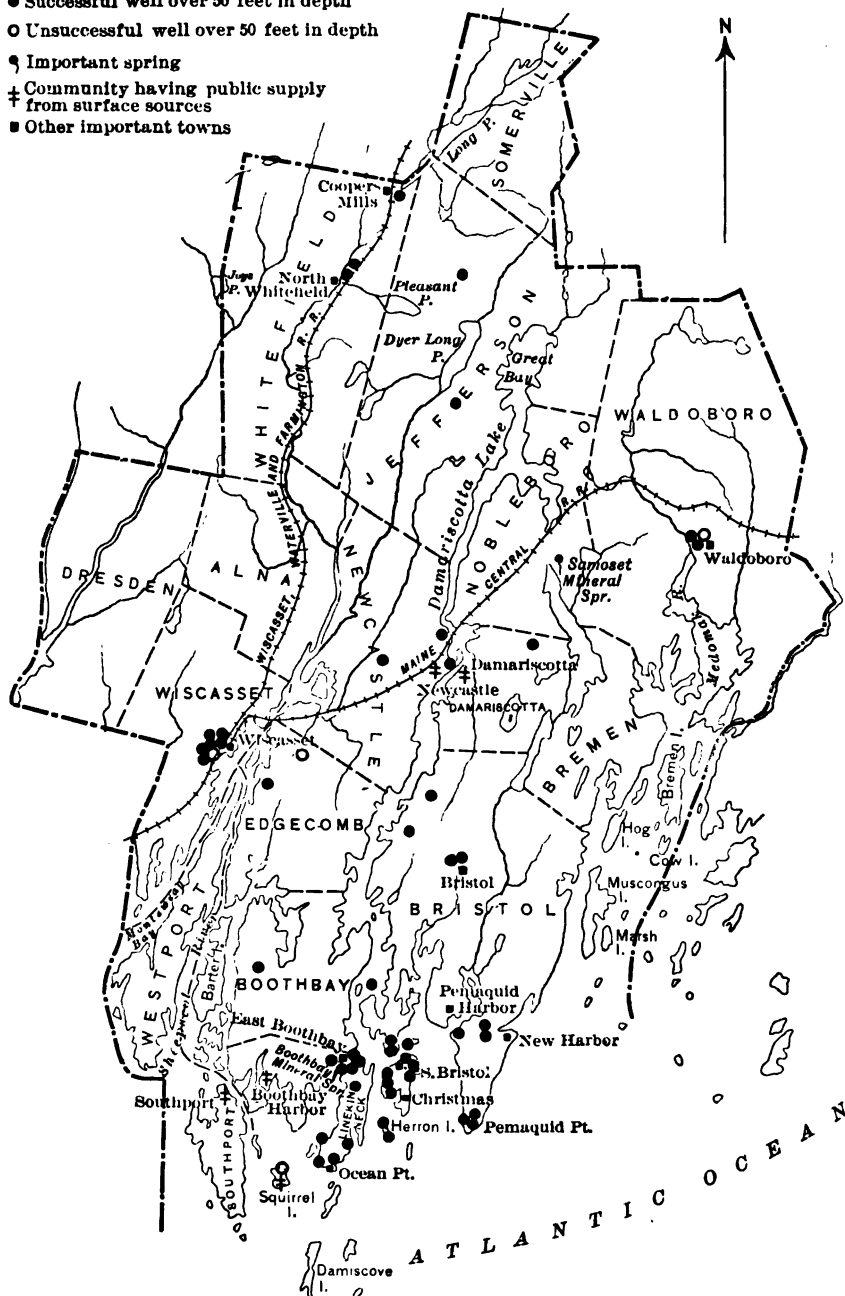
RELATION TO ROCKS AND SURFACE DEPOSITS.

Distribution of rock types.—Nearly the entire area of Lincoln County is composed of a complex of slate, schist, gneiss, pegmatite, etc. The greater part of the towns of Waldoboro and Bremen is, however, occupied by granite. Smaller granite areas exist within the limits of the complex, but they are for the most part not large enough to be mapped.

Character of rocks.—The rock complex of which most of Lincoln County is composed is similar to the areas of complex in other counties. Where outcrops are seen they may consist of dense schist, striking in a northeast-southwest direction and having a nearly vertical dip, or of granite or gneiss or pegmatite. In most places the exposures consist of a mixture of these types, perhaps with gradations between them. Here and there these rocks are intruded by masses of trap, diorite, or other igneous rocks. There are no quarries in the area of complex in this county or elsewhere in the State, and for that reason the actual conditions in which the water is held in the rocks are not well known. A few railroad cuts show water seeping out of horizontal joint cracks or along the contact between various types of rock. In some sections along the railroad the water is seen in cracks which have been opened by blasting. This would seem to indicate the desirability of "shooting" wells where no water is obtained. In general the occurrence of water in the area of complex is likely to be less abundant than in areas of granite or of slate. This is presumably due to the fact that the changes in character of the rock interfere with the circulation of water through definite joint cracks extending for long distances.

Surface deposits.—The surface deposits of this county are as a rule not of great thickness. The coasts are rocky, and the islands contain only a few feet of drift. Some exposures of clay are found along the valleys, and these may be expected in protected areas anywhere up to an elevation of 200 feet or so. Small areas of stratified sand and gravel also rise to the same altitude. Most of the uplands

- Successful well over 50 feet in depth
- Unsuccessful well over 50 feet in depth
- ☿ Important spring
- ⊕ Community having public supply from surface sources
- Other important towns



MAP OF LINCOLN COUNTY.

Showing distribution of deep wells, important springs, and communities having public water supplies.

of the county are covered by till, which varies in thickness from 1 to 20 feet or more. The thickest deposits of drift are probably in the vicinity of Waldoboro, where there are large moraines.

WELLS.

GENERAL DESCRIPTION.

The wells of Lincoln County consist of both dug and drilled types, the former being by far the most numerous, as in other regions. There are, however, more than 80 drilled wells within the limits of the county. These range in depth from 30 to 360 feet, and the usual size is 6 inches. The most common depth of wells in this region is somewhat less than 100 feet, and probably not more than 70 feet. There are, however, a few wells as much as 150 feet deep and three wells have been sunk more than 200 feet. In general the deeper wells are not so successful as those of moderate depth. The 360-foot well on Ocean Point is an exception to this rule, and in that well a large portion of the water was obtained near the bottom.

The quality of the water from deep wells in Lincoln County should probably be ranked lower than that of any other county in Maine. The most common defect is the large proportion of iron which it contains. This is shown in few analyses; it is in reality but a few parts per million, but is sufficient to give a distinct mineral taste to the water and sometimes makes the water too rusty to be used for washing. The mineral matter ranges from 95 to 419 parts per million, as shown by analyses Nos. 135 to 149 and 22 to 28 in the table. The water is generally called hard by the residents. Analyses of three mineral springs are given also (Nos. 256 to 258). No flowing wells are known within the limits of the county.

DETAILED DESCRIPTIONS.

Wiscasset.—As Wiscasset has not yet a public water supply, a considerable number of drilled wells have been sunk in the village. More than fifteen years ago a well was drilled for Mr. W. G. Hubbard at the Hilton House to a depth of 70 feet. At 68 feet a fine supply of water was struck, which can not be exhausted when pumped at the rate of 35 strokes a minute, and after eight or ten hours' pumping the well contains just as much water. It is supposed to yield about 15 gallons a minute. When first struck the water would fill the well at the rate of 15 feet in five minutes. It can be lowered 50 feet by pumping. A gasoline engine was installed and a well house and tank were built at a total cost of about \$1,000.

Another good well was drilled in 1905 at the custom-house to a depth of 75 feet, and water was struck at 72 feet, increasing in volume near the bottom of the well. It supplies the custom-house and half a dozen families for drinking and cooking purposes. This well was

cased 6 feet into rock, and at the surface of the ground a cement floor was put in as a preventive of contamination by infiltration of surface drainage. The water can be lowered, but it will return to its former level in ten minutes. Four hours' pumping will not exhaust it.

In the 48-foot well of Mr. S. B. Cromwell, at Wiscasset, the drill dropped 3 or 4 inches when water was struck, indicating the occurrence of joint cracks. Several wells between 30 and 50 feet in depth in this village have good supplies. Most of them can not be pumped dry. The water sometimes has a bad taste, which is believed to be due to its action on the galvanized-iron pipe, but may be due to the iron naturally contained in the water.

Two wells in Wiscasset, both situated at the Turner Center Creamery, only a block from tide water on Sheepscoot River and 5 feet above tide, have been spoiled by the entrance of salt water. One of them, 64 feet in depth, was drilled in 1890 for Mr. John Budd, who had a gristmill on the spot. After being used a couple of years the water became too brackish for use. A second well was drilled at the creamery to a depth of 103 feet. This is too brackish for drinking, but is used for cooling cream.

A well drilled for Mr. A. R. Smith is an example of a correct method of construction where rock lies near the surface. In this well the depth to rock is 6 feet. The surface materials were dug out and the casing was driven 3 feet into the rock and cemented firmly to the ledge, thus preventing all entrance of surface drainage.

The deepest well at Wiscasset is 154 feet deep, sunk at the county jail. This is another example of good construction. Rock reaches the surface here, and a pipe was put in and the rock coated with cement for several feet around the pipe. A laboratory analysis of the water from this well is given in the table (No. 149). Field assays of three other wells are also given (Nos. 146 to 148).

In brief, well drilling in Wiscasset seems to have met with marked success. Most of the families in town use dug wells, which give plenty of water the year round and have never seriously interfered with the public health. Many of these wells are in poor situations, however, and as the use of dug wells is always dangerous in a village, they should be abandoned and a public water system established without delay. Meanwhile drilled wells are highly recommended.

Edgecombe.—At South Newcastle, in 1901, Mrs. C. A. McMichael drilled a well 56 feet in depth. Water struck at that depth rose to within $1\frac{1}{2}$ feet of the surface, but the supply was small and the well was abandoned. No other drilled wells are known in town.

Newcastle.—The villages of Newcastle and Damariscotta are supplied with water by the Twin Village Water Company, obtaining its supply from Little Pond. The water seems to be of good quality. Throughout the town of Newcastle dug wells prevail, but several

drilled wells have been sunk. The two Glidden wells, 85 and 88½ feet in depth, struck water near the bottom and obtain 7 gallons a minute. They are pumped by a hot-air engine for domestic use. At Damariscotta Mills a well was drilled 64 feet deep for Mr. S. W. Waltz, and plenty of water was found for all ordinary purposes. An analysis of this water is given in the appended table (No. 24).

Damariscotta.—Damariscotta is situated just across the river from Newcastle, and the two villages have a joint supply from Little Pond. The supply seems to be good, and no wells have been drilled in the village. In the northeastern part of town a well was sunk for Mrs. S. G. Chapman to a depth of 87½ feet, and the principal water supply was obtained at 57 feet. The amount is said not to be large, but there is plenty for two houses and two barns, and it is reported to have increased during the course of years. A field assay is appended (No. 23). The water is said to become softer every year. The well is fitted up with a model type of windmill and tank, and the water runs by direct pressure to the house.

Bristol.—The town of Bristol covers a large area, and many drilled wells have been sunk within its borders. At Bristol Mills most people use dug wells and obtain fair supplies of water. A few persons have springs, one of which supplies three families. Wells have been drilled here for Dr. J. W. P. Goudy and Mr. J. C. Hyson, 52 and 62½ feet deep, respectively. Doctor Goudy's well obtains a plentiful supply of good water (analysis No. 22). It is pumped by a force pump situated inside the house, although the well is 10 feet away. There is a tank in the top of the house, and the owner has installed all modern improvements. The water at Bristol Mills is reported to be much better in quality than that at South Bristol.

In the northwestern part of the town Rev. H. E. Cotton has a well 72 feet in depth, but he obtained only about 1 gallon a minute.

At Pemaquid a well was drilled in 1901 for Mr. C. A. Sprowl to a depth of 45 feet. The principal water was struck at 30 feet, but it has a poor taste. The same trouble was experienced with the well of Mr. M. B. Macdonald. At this place nearly every house has a cistern. The well water is poor and very irony. On Pemaquid Point Mr. W. A. Elliott had a well drilled in 1901 to a depth of 51 feet, getting a good supply of water at that depth. The well supplies the hotel and probably 90 people during the summer. Two complete analyses of well waters from Pemaquid Point are given in the table (Nos. 145 and 145a). An analysis of water from granite at Pemaquid Beach is given also (No. 25).

At New Harbor there are several wells, 30 to 140 feet deep. The water is highly charged with mineral matter, has a bad taste, and is very destructive to the well casings. Mr. E. W. Fossett drilled a well 33 feet deep and put in galvanized-iron pipe. The water was

not fit to drink, and he changed to block-tin pipe. The water ate pinholes through this pipe, and it was necessary to resort to a wooden pipe. The water is still very irony, showing that the mineral taste did not come entirely from the casing.

At South Bristol several wells have been drilled, the water in most of which is very irony. In the well at Mr. N. W. Gamage's hotel rather bad conditions were encountered, and they are described for the reason that they have an important bearing on the purity of water in deep wells in general. At a depth of 2 feet from the surface a small slanting crack was encountered, which reaches the surface 5 feet from the well. The surface of the rock here was thoroughly covered by cement, but afterwards grass and worms were found in the well water, and an analysis by the State board of health showed a large amount of organic matter. It is supposed that these must have entered through an extension of the crack or through an intersecting crack on the other side of the well. On account of the poor quality of the water the well was temporarily abandoned for cistern water. In this well a small quantity of water was found at 30 feet, but the largest volume was encountered at 100 feet. The well was drilled 3 feet deeper to furnish a reservoir.

The largest group of wells in Bristol is found at Christmas Cove, on the south end of Rutherford Island. Here there are 13 drilled wells, ranging from 25 to 125 feet in depth. Several of these have an abundant supply of water and have never been pumped dry. One of the largest wells in Lincoln County is that of Mr. W. E. Little. The others range from 1 to 3 gallons a minute. The water is mostly of good quality, but rather hard, and some of it is a little irony. Two laboratory analyses are given in the table (Nos. 135 and 136). The well drilled for Mr. W. E. Little at the Christmas Cove House was sunk to a depth of 106 feet, rock lying about 22 feet from the surface. The water was obtained at 50 feet, but it was not sufficient in quantity, so the next year the hole was deepened and 2 gallons a minute were obtained. Most of the wells at Christmas Cove are ordinary open wells, some of which are blasted in rock.

On Heron Island, just off the point of Christmas Cove, are two wells, one of which, belonging to Mr. William C. Damon, is 115 feet deep. It can be pumped dry, but furnishes plenty of water for the use of a single cottage. A complete analysis of water from this well is given in the table (No. 142). On the north end of the island a well was drilled for the Heron Island Company to a depth of 162½ feet, and got plenty of water in wet weather, but not enough in a dry spell. This well is used to supply the hotel near by. It stands in a small depression in the surrounding rock, and the top of the casing is open, with nothing to prevent the entrance of dirt, stones, or small animals. (See p. 66.)

Boothbay Harbor.—The villages of Boothbay Harbor and Bayville are supplied by an excellent water system owned by the town and obtained from Adams Pond. No drilled wells are known to have been sunk in the town, but if it should become necessary to use well water it is probable that drilled wells would be successful so far as the quantity of water is concerned. As indicated by the conditions in neighboring towns, the water would probably be found to be somewhat irony.

Boothbay.—Most of the wells in the town of Boothbay have been drilled at East Boothbay. The Hodgton Brothers' well is 120 feet deep, but got most of the water at 47 feet from the surface. By looking down the well with a hand mirror water can be seen issuing from fissures in the rock. In quality it is called very good, and people from a number of houses use water from it. It is also used to supply a blacksmith shop here. Mr. Frank Rice, near by, has a well 75 feet in depth, which was first drilled 34 feet in 1905, but the amount of water was not sufficient, and the next year it was sunk to 75 feet, and a plentiful supply was obtained. The water has, however, a bad "vitriol-like" taste. An analysis is given in the table (No. 141). The water is sufficient to supply a dozen families. Mr. Frank Weston had a well drilled 75 feet deep, which obtained water at a depth of 65 feet from the surface. The well can not be pumped dry, but the water has the same bad taste. Capt. J. L. Race drilled only 35 feet, and his well yields plenty of water, but has the same defect. Field assays of two of these wells are given in the table (Nos. 139 and 140).

On Ocean Point three wells have been drilled, the deepest being that of Mr. L. J. Crooker. This well was first drilled only 60 feet, but the supply gave out in a dry summer; for that reason it was drilled the next year to 360 feet, and now there is plenty of water. The cylinder of this pump is down only to 120 feet, indicating that the head of the water sustains itself well. It is pumped by a gasoline engine and windmill. Most of the water is reported to come in near the bottom of the well. An analysis is given in the table (No. 144).

The well of Mr. John A. Royal, situated 1 mile northeast of Ocean Point, is 90 or 100 feet in depth and obtains its principal water supply at 85 feet. It is pumped by a hot-air engine and can not be exhausted. The owner has installed a 600-gallon tank and has all modern improvements in his house. On Lincoln Neck, about 1 mile east of East Boothbay, is a well belonging to Miss F. C. Lowden. This is about 250 feet in depth and obtains 10 gallons of water a minute, supplying two cottages. Two wells near together, 154 and 157 feet deep, situated near East Boothbay, were formerly used for manufacturing purposes, but were abandoned. The supply is variously reported as 3 to 27 gallons a minute, but the water was highly charged with mineral.

To summarize the conditions in the town of Boothbay, it can be said that the water as a rule is rather poor, having a strong mineral taste, which is probably for the most part iron, but which may come in certain wells from the zinc in the galvanized-iron casing dissolved by the water. In locations where the taste is not objectionable it will be advisable to sink wells, as the quantity of water is in general sufficient for ordinary purposes.

Southport.—The only drilled well known in the town of Southport was sunk on Squirrel Island for the hotel. It was drilled to a depth of 200 feet in granite, obtaining one-half gallon of water a minute at 40 feet from the surface. The supply was insufficient for the hotel, and the well has never been used. Water mains are now laid across the bay from Spruce Point, and the Boothbay Harbor supply is used for the hotel and cottages.

Waldoboro.—Two wells in the village of Waldoboro, belonging to Mr. R. L. Benner and Miss E. F. Genthner, are 56 and 88½ feet deep, respectively, in granite. The supply is about 5 gallons a minute in each, obtained from a depth of 48 and 84 feet, and the water is of excellent quality. Miss Genthner's well had a good supply of water at 30 feet, and the water level rose within 7 feet of the well mouth. On drilling 20 feet deeper, however, another crevice was struck, and the water level dropped 8 feet. The marked contrast in the quality of water here to that at East Boothbay and Bristol shows the superiority of water in granite to that in the region of complex. A laboratory analysis was made of one of these waters (No. 28) and a field assay of the other (No. 27). Mr. Benner has the pipe of his well cemented to ledge.

In 1904 a company was chartered in Waldoboro to sink a well for public supply on top of the moraine-like gravel hill east of the village. The well reached a depth of 200 feet, of which 176 feet were in rock, and yielded 10 gallons of water a minute. The funds of the company then gave out and the well was never completed. Most of the people in Waldoboro use dug wells, many of which give water of poor quality. The town is in great need of a public supply. Wells similar to the one drilled by the old company might be put down and a satisfactory supply obtained. The citizens have become discouraged in regard to well drilling, however, and are suspicious of putting money into any new scheme. It is possible that a satisfactory supply could be obtained from Storer Pond or some other pond at a distance from the village.

Whitefield.—At Coopers Mills, in the northeast corner of Whitefield, three wells have been drilled to depths of 46, 65, and 28 feet. In the well of Mr. S. E. Hopkins water was found near the surface and drilling was stopped. This well can be pumped dry in twenty minutes, but will fill again rapidly. The water is excellent for drink-

ing, but contains a little iron. A field assay is given in the table (No. 138). The wells of Mr. Charles H. Ashford and Mr. Newell Avery obtained sufficient water for domestic purposes, but the iron taste is noticeable; consequently Mr. Ashford uses his water only for drinking. A laboratory analysis was made of this water (No. 137).

At North Whitefield at least three wells have been sunk, that of Dr. A. R. G. Smith reaching 114 feet. All the wells here are of good quality except for the slight taste of iron.

Jefferson.—In the northwestern part of Jefferson Mr. Abram Brann had a well drilled to a depth of 91 feet, obtaining water at 25 feet from the surface, which is excellent for drinking, but a little irony. At Bunker Hill a well belonging to Mr. L. R. Hodgkins was drilled to a depth of 119 feet. This water also contains iron.

Other towns.—In the town of Alna at least one drilled well has been sunk, but no information regarding it could be obtained. In Somerville, Nobleboro, Bremen, and Dresden no drilled wells are known, and the conditions are such as are ordinarily found through the country districts. It is probable that supplies in these towns will be of similar quality to those found in other sections. On the island of Monhegan, situated several miles from the mainland, drilled wells are not known, but it would seem desirable to sink them, as supplies of fresh water could probably be obtained.

SPRINGS.

General statement.—Springs are fairly abundant in Lincoln County and are used by a number of farmers for private supplies. They can generally be obtained on steep hillsides, and most of them issue from deposits of boulder clay. There are no commercial mineral springs within the limits of the county, but reports have been received of two springs which are of some interest.

Boothbay Medicinal Spring.—At East Boothbay is a spring which is rather interesting, as the water is chalybeate, containing 20 parts per million of iron. The total solids amount to 212, and the constituents are given in the table (No. 256), recalculated from the owner's report of the analysis. The flow of this spring is reported to be 2½ gallons a minute. The water is sometimes carbonated.

Samoset Mineral Spring.—The Samoset Mineral Spring is situated one-half mile east of Nobleboro. The water is interesting, in view of the fact that it contains 425 parts per million of total solids—more than any other spring in Maine of which the water has been analyzed. (See analysis No. 258.) Of this, sodium constitutes 127 parts. As the chlorine is low, it is possible that there is considerable sodium carbonate in this water. This spring also contains 19 parts of iron, making it highly chalybeate. The flow is reported to be 2½ gallons a minute. The water is carbonated.

PUBLIC SUPPLIES.

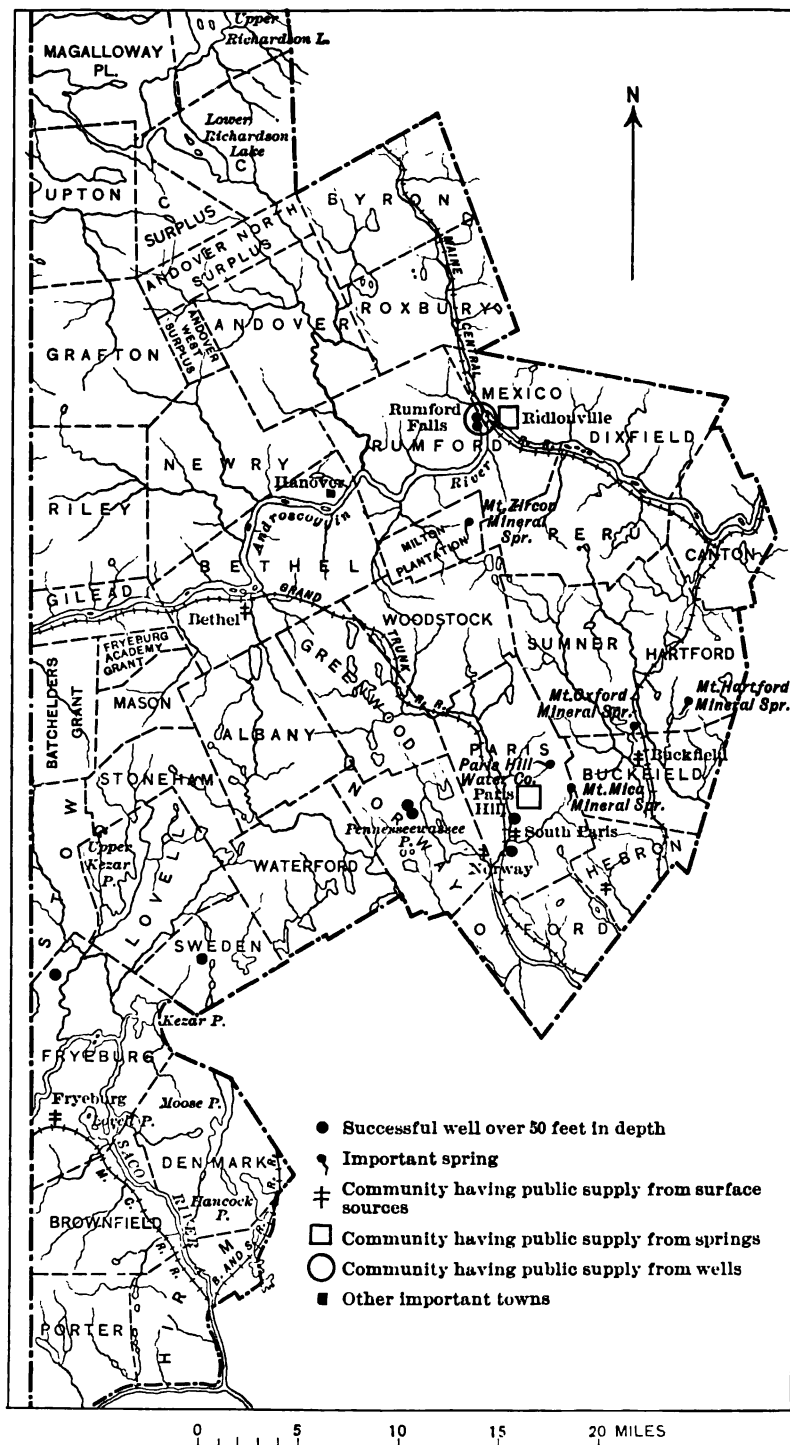
The towns of Lincoln County are so small that few have public supplies. The villages of Newcastle and Damariscotta have united to obtain a supply, brought from Little Pond by the Twin Village Water Company. Boothbay Harbor and Bayville have a supply from Adams Pond, and this is also piped under the bay to Southport and Squirrel Island. The town of Waldoboro once attempted to obtain a supply for the village by sinking a deep well, but there was financial trouble and the company was dissolved. Wiscasset has no public supply, but is greatly in need of one. Conditions in these towns are described under the various town headings.

PREDICTIONS AND RECOMMENDATIONS.

The villages of Lincoln County are so small that public supplies are less necessary than in some other counties. However, as already noted, Wiscasset and Waldoboro should install water systems as soon as practicable. As explained above, the supplies are poorer in this county than in any other part of Maine. This is due principally to the fact that the water comes from an area of complex in which the rocks are very irony, and it is inevitable that some of this iron content should be dissolved by the water. There are, however, within the complex area small patches of granite, ranging from a few feet up to several miles in extent. It has been found that water in these patches is excellent, in marked contrast to that in the areas of mixed rocks. Hence the principal recommendation to make for Lincoln County is that whenever possible a well be sunk in granite in preference to shale, schist, or any other metamorphic rock. The waters from granite have been found by analyses to be of high quality.

SOUTHERN OXFORD COUNTY.**GENERAL DESCRIPTION.**

Oxford County is situated in western Maine, bordering on the New Hampshire line; it is bounded on the north by Canada, on the south by York County, and on the east by Franklin, Androscoggin, and Cumberland counties. Its length from north to south is 110 miles, and its extreme breadth is about 40 miles. The area of the county is 1,981 square miles, and the population according to the census of 1900 was 32,238. Rumford Falls is the largest town, containing 2,595 inhabitants. This county is very hilly and in parts it is very mountainous. The elevation of the surface ranges from 300 feet on Saco River and 350 feet on Androscoggin River to 3,125 feet at the summit of Mount East Royce. Androscoggin River crosses the county from west to east near its center, and this river has its source in the same county farther north. Saco River crosses the southwest corner of the county. A large number of



MAP OF SOUTHERN OXFORD COUNTY.

Showing distribution of deep wells, important springs, and communities having public water supplies.

Lakes and ponds are scattered throughout the area, but the largest are situated near its north end. Welokennebacock and Molechunk-amunk lakes lie entirely within the county, and Umbagog and Mooselookmeguntic are largely included within its limits.

The county is comparatively well served by transportation lines. The Grand Trunk Railway crosses it in a general northwesterly direction from Lewiston in Androscoggin County to Androscoggin River on the boundary between Oxford County and the State of New Hampshire. The Maine Central Railroad crosses the southwest corner of the county, along Saco River from Fryeburg to Hiram. The Portland and Rumford Falls Railway extends northward from Mechanic Falls in Androscoggin County to Canton on Androscoggin River; it follows this river northwestward to Rumford Falls, and then extends northward into the wilderness. A small portion of the north end of the county, lying entirely in the wild lands, is outside the area considered in this report.

The deep wells, important springs, and communities having public supplies are represented in Pl. XVIII.

UNDERGROUND WATERS.

RELATION TO ROCKS AND SURFACE DEPOSITS.

Distribution of rock types.—The rocks of Oxford County fall naturally into two groups. In the first group belong the granites and associated gneisses and schists of the complex; in the second group belong the slates. West of a line drawn from a point near North Fryeburg northwestward to Locke Mills, and northward beyond Roxbury on the Portland and Rumford Falls Railway, the area is mostly a mixture of slate, granite, gneiss, etc., with the exception of a solid granite area entering from the vicinity of Rangeley Lakes and extending southward to the vicinity of Grafton, and one or two smaller granite areas. Southeast of the above-mentioned line the rocks are largely granite. They include, however, areas of gneisses, schists, and possibly other rocks which can not be differentiated on the map and which have not been studied in detail.

Structure and relations of rocks.—These rocks are similar to those of Androscoggin County. The granite is of diverse character, ranging from a very coarse grained typical granite to a fine-grained rock which is more in the nature of aplite. These rocks are cut by beds of gneiss and schist, and here and there mineral springs issue along the contact. Pegmatite, a very coarse grained granitic rock, which in places contains rare minerals, is abundant in Oxford County, but is found only in small bodies. This is the type of rock occurring at Mount Mica, in the town of Paris. The characteristics of the slate of Oxford County have not been studied.

Surface deposits.—The surface deposits of Oxford County consist largely of boulder clay, which ranges in thickness from a few inches on many rugged hills to more than 50 feet in other places. There are large deposits of gravel in the county, but, as might be expected, these occur mostly along the valleys. Clay in this county is rare. In the surface materials water is generally abundant, but is likely to give out in the dry season.

WELLS.

GENERAL DESCRIPTION.

Types of wells used.—Open wells are the most abundant type in Oxford County. These range in depth from 5 to 50 feet and are generally successful. Frequently, however, the supply of water is not sufficient in a dry season and it is necessary to resort to springs. In some parts of the county, where the surface deposits are soft enough, driven wells have been sunk a few feet, and many of these are successful.

Drilled wells.—Drilled wells are not abundant, and so far as known only about a dozen have been sunk within the limits of the county. Most of them are in Norway, Rumford Falls, and South Paris, but there are several in other towns. The most common size is 6 inches, but one 8-inch and one 12-inch well were reported. The depth ranges from 50 to 125 feet. Generally these wells have been successful in obtaining plenty of water for ordinary domestic use. Three of them, however—one in Rumford Falls, a second in South Paris, and a third in Sweden—are not used on account of insufficient supply. One of these three was the deepest well in the county. The wells are used mostly for domestic purposes, but at South Paris one well has been sunk to supply a factory with drinking water. The supplies are obtained mostly by hand pumps or windmills.

Quality of water.—One well was abandoned on account of a strong taste in the water, presumably coming from the galvanized-iron pipe used for casing. Otherwise the quality of water from the wells of Oxford County is as good as the average. Few analyses of Oxford County well water have been made. The most important, which were of water from driven wells at Rumford Falls, will be found in the table (Nos. 187 to 189) and are discussed on pages 183–185. Waters from several of the springs of Oxford County have been analyzed and the compositions are given in the table (Nos. 259 to 265).

DETAILED DESCRIPTIONS.

Rumford.—The village of Rumford Falls has a fair water supply from driven wells situated on the flood plain of Androscoggin River at the upper end of the village. (See pp. 184–185 and analyses 187 to 189.) With this exception few wells are in use in the village, and

only three drilled wells were found. The wells of the public water-works are from 20 to 35 feet in depth and are mostly in sand. The system is described in detail under the heading "Public supplies."

Dr. C. M. Bisbie once sunk a well in the upper part of the village to a depth of 73 feet. A little water was found at 25 feet from the surface, just below the top of the bed rock. The amount was considered insufficient and the well was abandoned. Other wells have been drilled, but no information regarding them could be obtained. At one time a well was started at a livery stable, but when the hole was down 6 feet the driller was required to give an expensive bond before proceeding, and this resulted in the abandonment of the work. Such requirements discourage well drilling, and it should be remembered that deep wells are a decided advantage to any community. It is probable that small amounts of water can be obtained by drilled wells in the rocks at Rumford Falls and vicinity. The upper part of the village of Rumford Falls, known as Virginia, is supplied by springs issuing from drift and piped to the houses. Mexico, across the river, is supplied by several aqueducts from springs on the hills, which supply 10 to 20 houses each.

A field assay of the water from a spring near the cataract is given in the table (No. 263). A few miles from Rumford Falls, in Milton Plantation, is the Mount Zircon Mineral Spring, described on page 182 (analysis No. 260).

Paris.—Paris Hill, the county seat of Oxford County, is supplied by springs, and wells are not much used. These springs are described on page 185 and the analyses are given in the table (No. 261). At South Paris several driven wells have been sunk. The best of these is probably the one drilled in 1906 for the Mason Manufacturing Company. It was sunk to a depth of 117 feet, 40 feet of which was drilled in sand and the rest in granite. The test showed 250 gallons of water an hour, and the quality was good. A well sunk for Mr. John H. Howland went to a depth of 122 feet in granite, but obtained little water. The well was "shot" with 90 pounds of dynamite without success. On the sand plain in the village of South Paris a number of driven wells have been sunk to depths of 10 to 30 feet. Some of these reach ledge. The wells got plenty of water and can not be exhausted. The public supply of South Paris is taken from Norway Lake and is used by a large number of people.

Buckfield.—The village of Buckfield has recently installed a good water supply, which is piped from South Paris. Formerly dug wells were extensively used in the village, but these are being abandoned, as the water is not as satisfactory for domestic purposes as the town water. Within a few miles of Buckfield, near the edge of the adjacent towns of Hartford and Sumner, are the Mount Hartford Mineral Spring and the Mount Oxford Spring, described

below and analyzed as reported in the table (Nos. 259, 259a, and 264).

Norway.—The water supply of the village of Norway, like that of Paris, is drawn from Norway Lake, and most of the people use it. A few persons use driven wells, and as the village is situated on the flat sand deposit only a few feet above the lake and river plenty of water can generally be obtained in this manner. Driven wells are better than dug wells and are advised outside the village. The desirability of their use in the village, however, is questionable, as, so far as known, the lake supply is satisfactory.

Sweden.—In the northern part of Sweden a well was once sunk to a depth of 189 feet on the farm of Mr. Walter Evans. It is reported to be drilled in "trap," and yielded 8 gallons of water a minute. As the farm is now abandoned, the well is not used, and no other information regarding it could be obtained. With this exception the wells are mostly less than 30 feet in depth and are ordinary open wells. The supplies are small, but there is enough water for farms, except in very dry weather.

Fryeburg.—In 1890 a well was sunk for Mr. L. W. Atkinson at North Fryeburg to a depth of 115 feet. There are some driven wells here, but most wells in the town are dug. Some families use cisterns to catch rain water.

Other towns.—With the exception of the towns described above, no localities in Oxford County are known to use wells of other than the ordinary open and driven types, which are mostly less than 40 feet in depth. These wells differ somewhat with the kind of material, but as a rule plenty of water can be obtained in wet weather, and smaller supplies, or none at all, in a dry spell.

SPRINGS.

General statement.—The springs of Oxford County are very numerous, occurring on steep hillsides, along the valleys, and even on gentle slopes. A great many of them are utilized by farmers for drinking. The water from others is bottled and sold in Boston and New York. The commercial mineral springs of the county are as follows:

Mount Hartford Mineral Spring, Hartford.

Mount Oxford Mineral Spring, Sumner.

Mount Zircon Spring, Milton Plantation.

Mount Hartford Mineral Spring.—The Mount Hartford Mineral Spring is situated in the southern part of the town of Hartford, about 4 miles northeast of Buckfield village, high up on the slopes of a granite hill. The spring is owned by the Mount Hartford Mineral Water Company, but is now leased for ninety-nine years to the Consolidated General Mineral Spring Company, of Philadel-

phia. The water seeps out of a boulder-clay hillside and is caught in a granite-walled tank and piped to a bottling house lower on the hillside. The water is shipped to Philadelphia and sold as the "Mount Hartford natural mineral water." It is colorless and odorless and is said to flow more than 40 gallons a minute. A large proportion of it is carbonated and made into ginger ale.

The water is low in mineral matter, as shown by the analyses (Nos. 259 and 259a). Analysis 259 is recomputed from the analysis given in the circular issued by the company. Analysis 259a is part of the following complete analysis, which was made by W. W. Skinner, of the Bureau of Chemistry, United States Department of Agriculture, in connection with cooperative work on mineral waters conducted by the Geological Survey and the Bureau of Chemistry.

Analysis of water from Mount Hartford Mineral Spring.

[W. W. Skinner, analyst.]

Gases (cubic centimeters per 1,000 grams at 0° C. and 760 mm. pressure):

Carbon dioxide (CO ₂), free.....	3.80
Carbon dioxide (CO ₂), set free from bicarbonates on evaporating to dryness.....	
	Parts per million by weight.
Phosphoric acid radicle (PO ₄).....	None.
Metaboric acid radicle (BO ₂).....	None.
Arsenic acid radicle (AsO ₄).....	None.
Silica (SiO ₂).....	9.00
Sulphuric acid radicle (SO ₄).....	1.62
Bicarbonic acid radicle (HCO ₃).....	20.47
Nitric acid radicle (NO ₃).....	.88
Nitrous acid radicle (NO ₂).....	None.
Chlorine (Cl).....	4.00
Bromine (Br.).....	None.
Iodine (I).....	None.
Iron (Fe) and aluminum (Al).....	Trace.
Manganese (Mn).....	None.
Calcium (Ca).....	4.43
Magnesium (Mg).....	1.03
Potassium (K).....	.76
Sodium (Na).....	3.95
Lithium (Li).....	None.
Ammonium (NH ₄).....	Trace.
Oxygen to form Fe ₂ O ₃ and Al ₂ O ₃	
	46.14
Free ammonia.....	Traces.
Albuminoid ammonia.....	Traces.
Nitrogen as nitrates.....	200
Nitrogen as nitrites.....	None.
Oxygen consumed.....	8.00

Mount Oxford Mineral Spring.—Mount Oxford Mineral Spring is situated in the town of Sumner, about midway between the villages of East Sumner and Buckfield, on the line of the Portland and Rumford Falls Railway. It is owned by the United Mineral Springs Company, of New York. The water issues from a steep boulder-clay hillside, far from all sources of pollution. The hillside above is wooded. There is no color or odor, and only a slight taste. The flow is estimated as 8 gallons a minute. From the granite tank in which it is caught, and which is covered with a glass case, it is piped down the hillside to a bottling house on the railroad at Saunders Crossing, whence it is shipped. The storage tank is 40 feet below the spring and holds 4,000 gallons. Most of the water thus far (1906) is shipped to Providence, R. I., but some of it is sent to Philadelphia. The pipe used in carrying the water from the spring to the bottling house, a distance of 80 rods, is of wrought iron, this kind of pipe having been recommended by the State chemist of Massachusetts as the best for this water. The water has been analyzed and is low in mineral matter. The composition recomputed from that reported in the circular issued by the company is given in the table (No. 264).

Mount Zircon Spring.—The Mount Zircon Spring is owned by the Mount Zircon Spring Company, of Boston. It is situated in the eastern part of Milton Plantation, high up on the western slope of Mount Zircon. It seeps out of boulder clay on a gentle, wooded hillside, somewhat higher than the only house in the vicinity. The water has no color, odor, or taste, and is reported to flow 14 gallons a minute. It is bottled on the spot and shipped to the city. A 5-gallon carboy of it retails in Boston for \$1.50. This is a very old spring, and is said to have been a popular resort long before the Poland Spring was known. There was formerly a large hotel here, which was well patronized until it was burned. The spring is inclosed in a small house, in which is a glass-covered porcelain-lined tank with a sand bottom, out of which the water bubbles. This water contains 33 parts per million of mineral matter, as shown in the analysis (No. 260), which was recalculated from the analysis reported in the circular issued by the company.

Cataract Spring.—On the west side of the cataract at Rumford Falls is an excellent spring, issuing from a flat crevice one-fourth inch in size in a pegmatite ledge, about 2 feet below the surface. The spring is situated just below the highway, above which the hill rises very steeply. The country rock is a complex. This spring is owned by the Rumford Falls Power Company, which does not use it, but many of the inhabitants haul the water for drinking, preferring it to the city water. The flow is about 3 gallons a minute. The highest temperature at the point of emergence in August was 45½°.

The spring is surrounded with granite curbing 10 feet across, cemented to the rock, and a small house protects it. The only analysis available is a field assay given in the table (No. 263).

Mount Mica Mineral Spring.—The Mount Mica Mineral Spring is situated on the southern slope of Mount Mica, near the boundary between the towns of Paris and Buckfield. The water bubbles out of sandy boulder clay at an estimated rate of 1 or 2 gallons a minute. It has no color, odor, or taste. It is not sold, but people frequently carry it away in bottles for their own use. The water is reported to have been analyzed, but the analysis has not been received by the Survey. A field assay is given in the table (No. 262).

"Magnesia Spring," Buckfield.—In the western part of Buckfield there is a spring which is reported to contain a large amount of magnesia. The water is not sold, but is carried away in bottles by a number of residents in the vicinity and is said to have medicinal properties. It is reported to have been analyzed, but no analysis has been obtained by the Geological Survey.

Jones's Spring.—About one-half mile west of Norway is Jones's Spring, the water of which is sold in Norway. The flow is small, being reported as only one-half gallon a minute.

PUBLIC SUPPLIES.

General statement.—The towns of Buckfield, Bethel, Fryeburg, Hebron, South Paris, and Norway have public supplies taken from surface sources. Paris Hill and the little town of Ridlonville use springs situated much higher up on a neighboring hillside, and Rumford Falls has a system of driven wells. The underground supplies will be described in detail.

Rumford Falls.—The water supply of Rumford Falls was formerly taken from Androscoggin River, but two years ago a system of 2½-inch driven wells was sunk at the upper end of the village, below the settlement known as Virginia. The wells are 68 in number and range from 22 to 35 feet in depth. They are about 30 feet apart, in sand and gravel that form the plain bordering the river, and are situated along a line 300 feet from the river. The system is owned by the Rumford Falls Water and Light Company. From the pumping station the water is pumped to a standpipe on the hill, with a capacity of 500,000 gallons and an elevation above the surface of 75 feet. The water is carried in cast-iron pipes and distributed by gravity from the standpipe. There are said to be 440 connections, which include most of the houses in town. Water to the amount of 1,164 gallons a minute can be pumped by the present plant, and this rate is continued twenty-four hours a day. There seems to be an abundant supply of water and as yet there has been no trouble about obtaining it.

The principal problem connected with the supply is its quality. Androscoggin River, situated close by, is of course polluted by drainage from the mills and towns farther up the stream. In addition to this factor, there is a swampy depression situated 50 feet east of the eastern line of the wells, and this depression lies downhill from the village of Virginia, in which the drainage conditions are poor. The water has a "mucky taste" and sometimes a little color in summer, and these defects have been supposed by residents of the city to be due to this depression.

An interesting case connected with this supply was reported by the manager of the water company. The inhabitants of the village objected to the water from time to time for the reason that it was supposed to be contaminated. In 1905 a series of samples were collected and submitted for analysis to Prof. F. C. Robinson, of Bowdoin College. The results of these analyses are given in the table (Nos. 187 to 189), in which sample 1 was taken from the pumping station, sample 2 from the end of a long galvanized-iron main, and sample 3 from Hotel Rumford. These analyses show that the total solids are rather low. In sample 2 there were 20 parts per million more than in 1 or 3. The chlorine, silica, calcium carbonate, sulphates of sodium and potassium, and sodium chloride are the same or very nearly so in all three analyses, but the carbonate of iron differs. The one surprising discrepancy in the analyses is that the amount of carbonate of zinc reported is 1.084 parts in sample 2, which was taken from the galvanized-iron main, while samples 1 and 3 showed no zinc. It is also noticeable that the carbonate of iron is greatest in the same sample and next greatest in the sample taken from Hotel Rumford, while the iron in the water at the pumping station is small. This seems to indicate, as stated by Professor Robinson, that the water in traveling through a galvanized-iron main dissolves a considerable quantity of the zinc, owing to the carbon dioxide in the water. This gas is more often present in well water than in river or lake water and is a desirable constituent, but it seems to have a bad effect on the water by dissolving the zinc. The iron causes a deposit when the water stands. The zinc renders the water unfit for domestic use and is probably the cause of some of the taste which is reported. For this reason Professor Robinson recommended that galvanized-iron connections be taken out and connections of tin-lined or brass pipe be substituted. The brass pipe is probably the best, but is more expensive. The bacteria in the water are all harmless. As seen by the analyses, they were most numerous at the pumping station and decreased rapidly toward the points where the water was used. The results of these analyses seem to indicate strongly that the taste complained of was due to the use of galvanized-iron connections.

Another recommendation made by Professor Robinson was that the swampy depression back of the wells should be filled up, as it affords a reservoir for stagnant water, and in the future may cause pollution of the wells. This recommendation is here reiterated, and it can not be too strongly urged that the conditions in the village of Virginia be kept as sanitary as possible in order to prevent any possible contamination of the public water supply. The pipes connecting with the mains in the streets are 16 inches in diameter, but in the distant parts of town the mains are as small as 6 inches. There is 1 mile of 16-inch pipe, and in all there are about 5 miles of pipe. Black iron pipe is used at present, and it seems to give satisfaction. There is now a regulation of the company which does not allow plain iron, lead, or galvanized-iron pipe as connections. Water rates are \$8 a year for ordinary faucets. The pressure on the main street is reported as 70 pounds. A test made of the pumping plant showed that 300,000 gallons of water could be pumped by it. This calls for only 25 gallons a minute from each of the 68 wells.

The strata found in the wells consist of 18 to 25 feet of fine sand at the top, below which is 10 feet of fine gravel, in which the water occurs; below this is another layer of fine sand. The water in the wells stands higher than in the river, indicating that it is not derived from that source, but comes from back in the hills.

Paris Hill.—The Paris Hill Water Company was incorporated and a gravity system of waterworks from Crocker Hill Springs was installed in 1899. The springs are situated on the side of a high hill about 2 miles east of the village. The water flows through a 2-inch cast-iron pipe to a reservoir 100 feet below the springs and 210 feet above the village. The pressure is 90 pounds. Water mains 8, 4, and 2 inches and service pipes three-fourths inch and one-half inch in size are used, and the total length of the mains is nearly 3 miles. There are no fire hydrants, but there are 70 taps, and about 350 persons, or approximately 95 per cent of the population of the village, use the public supply. It has been estimated that 5,000 to 15,000 gallons of water are used daily. The supply is sufficient for all present needs.

The Crocker Hill Springs seep out of gravel far removed from any source of pollution. The water is of as good quality as any other in Maine. Analyses made in 1901 for the owners by a New York chemist (name unknown) and recalculated by the United States Geological Survey are given in the table (No. 261). The amount of total solids—11, 13, and 14 parts per million—is extremely low. Samples 1 and 2 were taken from the reservoir and sample 3 at the residence of Mr. George M. Atwood, at Paris.

Ridlonville.—The Shaw-Ridlon Land Company, of Ridlonville, owns a water supply derived from springs. The water is used only for domestic purposes and is satisfactory, but fire protection is needed.

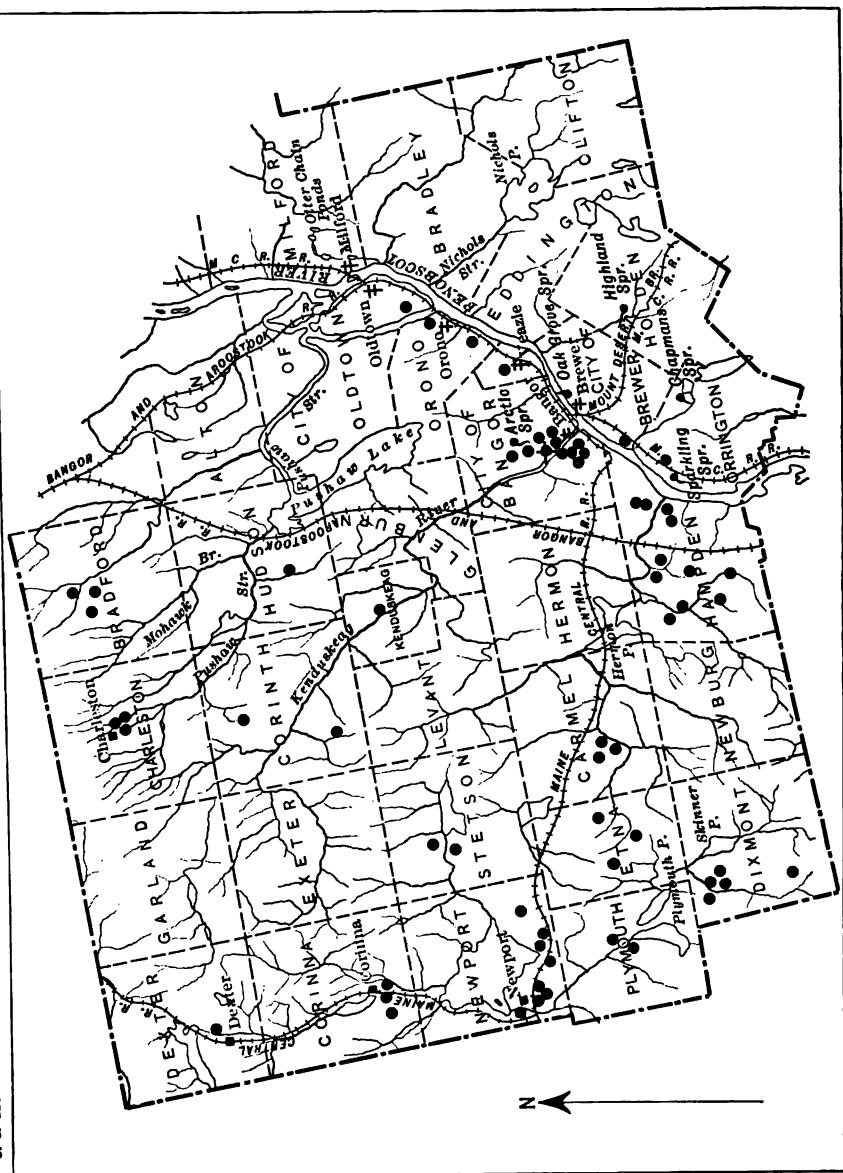
SOUTHERN PENOBSCOT COUNTY.**GENERAL DESCRIPTION.**

Penobscot County lies somewhat east of the center of Maine and has a length of 120 miles, extending from near the head of Penobscot Bay northward into the wilderness. Its greatest breadth east and west is about 70 miles, and its area is 3,254 square miles. Only the southern portion is covered by the present report. The northern border of this area lies near Oldtown and Charleston. The population of Penobscot County according to the census of 1900 was 76,246. The largest city is Bangor, with a population of 23,500, and Oldtown comes next with 5,763 inhabitants. This county is moderately hilly. Its elevation ranges from sea level to nearly 5,000 feet on the eastern slopes of Mount Katahdin, many miles north of the area covered by this report. In the area under consideration the greatest elevation is only about 1,000 feet, in the southeast corner of the county, on the edge of the mountains. Scattered throughout the county are a great many lakes, of which the largest are Newport Pond, Pushaw Lake, and Nichols Pond. Penobscot River flows through the center of the county from north to south, and on it are situated Bangor, Oldtown, and a number of the other principal towns. The Maine Central Railroad crosses from west to east between Dover and Bangor and then runs northward along Penobscot River. This railroad has a branch running from Bangor southeastward to Ellsworth, in Hancock county, a second branch running southward along Kennebec River to Bucksport, in Hancock County, and a third extending northward from Newport to Dover, in Piscataquis County. The Bangor and Aroostook Railroad runs northward from Waldo County, and crosses the center of Penobscot County to South Lagrange, where it joins a branch of the same road which connects with the Maine Central Railroad at Oldtown. The locations of deep wells, important springs, and communities having public supplies are shown in Pl. XIX.

UNDERGROUND WATERS.**RELATION TO ROCKS AND SURFACE DEPOSITS.**

Character and distribution of rocks.—Nearly the entire portion of Penobscot County included within this report is composed of slate. The only exception is a patch of granite which lies in the extreme southeast corner of the county, entering it for only a few miles in the mountain region. The slates which cover the county are typical of the class of slates which cover large areas in central Maine. They are fine grained and split parallel with the stratification, which is nearly vertical and strikes very uniformly in a direction about N. 30° E. Here and there dips of as much as 60° toward the southeast or northwest are found. In places numerous quartz veins are seen parallel with the stratifica-

- Successful well over 50 feet in depth
- ✦ Flowing well
- Important spring
- ✦ Community having public supply from surface sources
- Other important towns



MAP OF SOUTHERN PENOBSCOT COUNTY.
Showing distribution of deep wells, important springs, and communities having public water supplies.

tion, and these indicate that in past geologic ages a great deal of water has circulated in the rock. The fact that many bedding and cleavage planes are rather open near the surface indicates the possibility that a large proportion of the abundant water now found in these slates is held in these planes. Some of the water, however, occurs in joint cracks, an examination of the rock where it is quarried showing that there are abundant cracks in other directions than the cleavage planes which might hold water.

At Brewer the direction of the principal system of joints is northeast and the hade about 50° SE. A second system strikes southeast and hades about 30° SW. A road cut at this place shows considerable water seeping down along the cleavage planes. The general structure of the rock can also be well seen at a number of quarries along Kenduskeag Stream at Bangor.

Surface deposits.—The surface deposits of Penobscot County differ greatly in thickness and character. Along Penobscot River the sands and gravels are locally as much as 100 feet in thickness, and some rather extensive areas of clay extend up the side valleys for several miles. Away from the river the gravels may be as much as 50 to 100 feet thick in exceptional cases, but they generally occur in the form of eskers, morainic deposits, and irregular patches of gravel.

Underlying the sands, gravels, and clays and overlying the bed rock almost everywhere is the regular boulder-clay deposit which is found nearly everywhere in Maine. This ranges in thickness from a foot to more than 50 feet. Along Penobscot River in the vicinity of Veazie are long sections showing nothing but boulder clay. Some of these are as much as 60 feet in height above the river. The upper part of this section is of a buff color for about 10 feet from the surface, and below that is the ordinary hard blue boulder clay. There are a great many boulders in the deposits, some of them up to 3 feet in diameter. No stratification can be seen in this type of deposit.

On a hill in the southern part of Orono a well was once dug for Mr. N. W. Page to a depth of 54 feet. This well passed through nothing but hard boulder clay and found no water until near the bottom.

WELLS.

GENERAL DESCRIPTION.

Types of wells used.—Although the old-fashioned type of dug well is very abundant in this county, as elsewhere in Maine, and far predominates in number over all other types, drilled wells are more widely scattered and are used by a larger number of people than in any other county in southern Maine. In the area under consideration there are supposed to be only two or three towns which contain no drilled wells, and in these towns there is no reason why drilled wells should not be successful.

Drilled wells.—The drilled wells which have been sunk in Penobscot County are mostly 6 inches in diameter, this being the most common size used in Maine. There are a few, however, which are reported as small as 4 and 5 inches. Several 7-inch wells have been drilled, and a well in Stetson, one of the oldest drilled wells in the State, is said to be 12 inches in diameter. A few wells are larger at the top than at the bottom, and a number are drilled in the bottom of dug wells, but this type is not recommended. The proportion of successful wells in Penobscot County is probably larger than in any other county in Maine. Altogether more than 85 wells have been drilled to depths greater than 50 feet, and it is not supposed that more than half a dozen of them have been abandoned for want of sufficient water.

Quality of water.—Only one well is known in Penobscot County with the mineral content so high that the water can not be used. A number of wells are reported, however, that have been contaminated by surface drainage and thereby rendered dangerous. As more analyses have been made of water from slate wells in Penobscot County than in any other slate area in Maine, a fair knowledge of the quality of water is available. Of 35 analyses which have been made, 8 are nearly complete laboratory analyses, the rest being field assays and tests for only a few constituents. All analyses will be found in the table (Nos. 72 to 106). As will be seen, the total solids range from 74 to 834 parts per million, depending largely on the proportions of lime, sulphates, and carbonates in the water. The highest lime recorded is 214 parts per million in the well at the Bangor House, but no other reports exceed 82 parts. Several wells report 5 to 10 parts per million of iron, but this is believed to be an error, as no iron can be tasted in these waters, and these figures should possibly be placed under "iron and alumina." Analyses of several spring waters are given in the table (Nos. 266 to 268). The waters of Penobscot County are as hard as any others in southern Maine, the hardness being in many waters from 100 to 300 parts per million.

DETAILED DESCRIPTIONS.

Bangor.—As the present water supply of Bangor is taken from Penobscot River it is badly contaminated by sewage and manufacturing wastes from Oldtown and other villages. Hence the problem of obtaining water from wells in the city is very important. Some persons still use dug wells, but the most popular type and the type advised in nearly every case is the drilled well. Within the city limits 13 drilled wells have been sunk; they range in depth from 30 to 425 feet.

The deepest well in Bangor, one of the deepest successful wells in Maine, is situated at the Eastern Maine Insane Hospital, 1 mile east of the city proper. This well was drilled in 1896 to a depth of 425 feet. A little water was struck at 50 feet, but the principal supply was

found at the very bottom of the well when all hope of success had been given up. The drill made a perceptible drop at the time the principal seam of water was struck. The water does not stand within 200 feet of the surface, but notwithstanding this fact 30 gallons a minute, the full capacity of the pump, can be obtained. Three hundred or more people are supplied for drinking and laundry purposes. Analysis No. 75 is a field assay of water from this well. When used in the laundry the water has to be softened.

Some of the best wells in Bangor were drilled during 1906 at the various schoolhouses in the city. The contract between the city and the drillers specified in every case that they must get at least 2,000 gallons of water a day. Wells are situated at the high school, the Palm street school, the Larkin street school, and the Union square school, and all have been successful in getting an inexhaustible supply of fine water. The depths vary from 72 to 217 feet, the deepest wells being generally the best. The water is not only used for drinking every day by the school children and by hundreds of passers-by, but, in the case of the high-school well at least, it has been used extensively by several hotels and numerous residences in the vicinity for their tables. On hot summer days this well is pumped almost continuously from morning till night without exhaustion. At Palm street, in a test, the well was pumped continuously ten hours a day for three days, and the water level was not affected. Careful sanitary analyses have been made of the schoolhouse wells, with the result that they were found to be perfectly safe for drinking. Mineral analyses have been made which show considerable discrepancy in certain wells, but are a good index to the character of the water beneath Bangor. (See Nos. 76-79, 86-87, and 90-91 of the table.)

Another excellent well, sunk in 1905, is that of Mr. F. L. Jones, on Center street. This well is 247½ feet deep; at this depth the drill dropped several inches and obtained water. The supply is so large that scores of neighbors use the well almost continuously. (See analysis No. 81.) The well at the court-house, which was the first well drilled in the city proper, and that of the Bangor House also furnish abundant supplies. In the latter well the drill penetrated 30 feet of clay, 15 feet of "rock," 5 feet of sand, and 240 feet of rock. As sand is very seldom found below solid rock, it is probable that the material below the clay is either an overhanging ledge or a large boulder. The Bangor House well is said to yield 27 gallons a minute. Analyses of water from this well (No. 73) and from the court-house well (No. 88) are given in the table. Water from the well of the Maine Creamery Company is sold in Bangor under the name of Hopkins Artesian Spring water. It is believed to be excellent water. (See analysis No. 84.) The amount of total solids is only 86 parts per million, the lowest reported in analyses of Bangor wells.

One flowing well has been obtained in Bangor. This was drilled in 1906 for Morse & Co., to supply drinking water for the men at their mill. The well is situated in the valley, only a few feet from a steep, rocky hillside. The water is pumped, but will rise 2 feet above the surface without pumping. It is of excellent quality and appears to be inexhaustible. It can be pumped down 75 feet in half an hour.

The conditions in the country districts of Bangor have not been extensively investigated. Some drilled wells less than 50 feet in depth are known, and it is probable that there are some of greater depth. At any rate, conditions are very favorable for getting deep supplies.

There is a persistent belief among residents of Bangor that a limestone formation underlies the city and is encountered by certain deep wells. This is presumably due to the fact that the well waters are mostly very hard, ranging in many wells between 100 and 300 parts per million. The hardness is due in these cases, however, to the solution of small amounts of calcareous material scattered through the slates and not to any regular bed of limestone.

Brewer.—Several drilled wells have been sunk in the town of Brewer, but only two of them are deep. These were drilled in 1899 for the Eastern Manufacturing Company, at South Brewer, and reached depths of 250 and 350 feet. The water is used for cooling acid at a pulp mill. The joint supply of the two wells is reported to be only 50 gallons an hour. The wells are situated not far from Penobscot River and the 350-foot well fluctuates with the tide and is reported to yield salty water. No drilled wells more than 30 feet in depth are known in this town, but as all wells in Bangor have been successful, drilling on this side of the river is likely also to be rewarded with success.

At South Brewer a number of springs are used for supplying houses. Some of these springs are in boulder clay, others issue from hard gravel underneath clay. One dug well in the valley of Sedgeunkedunk Stream was dug through 19 feet of clay and 3 feet of gravel, and the water rose to the surface and overflowed, thus being truly artesian. A pipe was inserted below the surface and the water carried to houses in the valley. Where good spring water can be obtained from uncontaminated sources it should by all means be used in preference to river water. Dug wells or springs in the villages are not advised, but drilled wells will obtain water which is pure and safe. Oak Grove Spring is situated in this town.

Veazie.—The people of Veazie, except those who have the public supply from Bangor, use dug wells. It is probable, however, that plenty of good water can be obtained by drilling into the underlying rocks.

Orono.—Near the southern corner of Orono a well was once dug, for Mr. N. W. Page, to the unusual depth of 54 feet. The well is situated on a round hill of boulder clay 200 feet above the river. The material is all hard, stony boulder clay, similar to that exposed in the section on the opposite bank of Penobscot River. On account of the tough nature of the material, it was necessary to blast with dynamite. The principal water bed was found at 30 feet, and the water seeps in everywhere lower down. The bottom of the boulder clay was not reached. A field assay of this water is given in the table (No. 173).

The village of Orono is supplied from Penobscot River, the water-works having been only recently installed. Several drilled wells supply moderate amounts of water from depths of 50 to 60 feet. One of these is situated at the University of Maine. It seems probable that larger supplies may be expected by sinking 100 to 200 feet deeper.

Oldtown.—Oldtown lies on the northern border of the area covered by this report, and its water supplies have not yet been investigated. No wells have been reported by correspondence, but as the rock conditions are similar to those of Bangor, where abundant and excellent supplies are found, it seems probable that like success will attend deep drilling at Oldtown.

Orrington.—Several shallow drilled wells have been sunk in the town of Orrington, getting water at about 50 feet, in slate. The best example is the well of Mr. Archie Harding, in the southern part of the town. When the well was sunk a large stream of water is reported to have gushed into it and rose 40 feet from the bottom. This well was pumped with two pumps and could not be lowered appreciably. The quality of the water is excellent. A field assay is given in the table (No. 105). Every evidence seems to favor well drilling in this town.

Hampden.—At scattering points in the town of Hampden a number of wells have been drilled, ranging in depth from 50 to 103 feet. There seems to be plenty of water for all domestic and farm purposes. In water from one of these wells a small amount of iron is reported. Four field assays (Nos. 100–103) were made in this town. In the square at Hampden Corner is a well 28 feet deep, belonging to the town. It was blasted in slate. As many as 20 families are said to use it, but it is exhausted during a drought.

Newburg.—No well reports from Newburg are at hand. The town is situated in rocks similar in nature to those at Bangor, however, and deep drilling here may be expected to be generally successful.

Hermon.—In Hermon the wells are mostly between 10 and 25 feet in depth, and they yield a fair amount and quality of water. Drilled wells are not known, but they will probably be successful if drilled deep enough.

Carmel.—In the town of Carmel a number of drilled wells have been sunk, from 45 to 75 feet in depth. The supplies are small, being generally only 2 or 3 gallons a minute, but there is generally enough water for domestic purposes. In one well it was reported irony, but otherwise it is good.

Dixmont.—At North Dixmont a number of drilled wells have been sunk, from 50 to 120 feet in depth, mostly of which yield sufficient water for domestic purposes. A single field assay was made (No. 104). In this part of the county the level of water in many shallow drilled wells varies with the season.

Etna.—A number of wells are reported in Etna from 40 to 100 feet in depth. Water is obtained at two or more levels, but the most abundant supplies occur near the bottom of the wells. In one well, 54 feet in depth, the principal seam of water was struck at 50 feet, a minor seam at 20 feet, and the yield is reported to be 15 gallons a minute. There is generally plenty of water for domestic and farm purposes. One well reports a little iron in the water.

Plymouth.—Conditions in Plymouth are similar. Well records are lacking, but it is known that water can usually be obtained in slate at depths of 50 to 100 feet. The supplies are generally sufficient for domestic and farm purposes, and the water is of good quality.

Newport.—Drilled wells are also used in Newport. They range in depth from 50 to 100 feet. Some of them are drilled in the bottoms of open wells, but this is a poor construction. (See p. 54.) The principal seams of water are encountered at all depths from 15 to 70 feet. One well, 79 feet in depth, struck the principal seam at 70 feet and a minor seam at 35 feet, and the total yield was 30 gallons a minute, but this is exceptionally large. In general there is enough water for a house and farm. Some data regarding the character of the water in East Newport are afforded by a laboratory analysis (No. 99), two partial analyses (Nos. 97 and 98), and one field assay (No. 96). The hardness and total solids are extremely high for Maine.

Stetson.—Several drilled wells have been sunk in Stetson. One of these is rather exceptional in being 12 inches in diameter. It is 74 feet deep and was sunk in 1878, getting water at the bottom. Another well, 100 feet in depth, was drilled in the bottom of a dug well and found no water. One complete analysis has been made of water from this town (No. 106).

Levant.—The wells in Levant are reported to be all dug, and the depths run from 8 to 25 feet. The quality of the water is as good as is usual in dug wells.

Glenburn.—No drilled wells are reported in Glenburn, but it is possible that one or more of them may exist. The proximity of this town to Bangor and the similarity of the slate make it probable that water of like quantity and quality will be found.

Kenduskeag.—A number of wells have been drilled in the town of Kenduskeag, and at least one of them is more than 100 feet in depth. This was sunk for Mr. Chester Weld and was dug 9 feet, blasted 13 feet, and drilled 86 feet in rock, the drilling being done in instalments, as the well repeatedly went dry. At the depth of 109 feet drilling was stopped, the supply being then 1 gallon a minute. Particulars regarding other wells in this town are not known, but it would seem probable that more water can generally be obtained by drilling deeper.

Corinna.—Drilled wells in Corinna are from 60 to 110 feet in depth. As a rule, sufficient water is obtained for domestic uses, and the quality is good. One well, however, 108 feet in depth, obtained water which was reported to be "salty," and was so poor that it could not be used. A field assay of one sample of well water is given in the table (No. 95).

About ten families in the village of Corinna are supplied by springs owned by Mr. F. F. Burrill. The supply was installed in 1897 and the water flows by gravity to the houses.

Corinth.—A few drilled wells are known in Corinth. They run from 35 to 70 feet in depth and supply plenty of water for domestic purposes. One well at East Corinth, drilled years ago, was a failure, but there is no reason why deep drilled wells should not generally be successful in this town.

Hudson.—A single well is reported in Hudson. It was drilled to a depth of 66 feet and gives enough water for ordinary domestic and farm purposes. Deep drilling in this town ought to meet with success.

Charleston.—Drilled wells in Charleston range from 16 to 190 feet in depth. Some of the shallower ones get plenty of water, but the deeper ones are the best. In this vicinity the water stands at 4 to 12 feet from the surface. Some wells can be pumped dry by continued pumping, but most of them can be lowered very little. One well, situated on the hill north of the village and 100 feet or so above the houses, was sunk for the Higgins Classical Institute to 105 feet, and the water stands 8 feet from the surface. It is siphoned down the hill to several houses in the village. There is abundant water and it can be lowered only 20 feet or so by pumping. The table includes a laboratory analysis of this water (No. 93) and field assays of the other well waters (Nos. 92 and 94).

Garland.—No information is at hand with respect to wells in Garland. The rock formation being similar, it seems probable that the conditions for obtaining water will be like those found in Charleston and that the supplies will be both abundant and good.

Dexter.—The village water supply of Dexter is taken from Dexter Pond. One drilled well is reported here 58 feet deep, but only a small amount of water was obtained. Conditions ought to be favorable for getting plenty of water by drilling 100 to 200 feet in the slate.

Other towns.—In towns east of the river, with the exception of Brewer and Orrington, there are no drilled wells. For a number of miles north of the area included in this report there are scattering drilled wells, and they generally obtain plenty of water. Northeast of the area the region of abundant water supply continues into Aroostook County.

SPRINGS.

The springs of Penobscot County are fairly numerous, although not so thickly distributed as in some parts of Maine. In the vicinity of Bangor are several mineral springs which supply water for many of the inhabitants. The commercial springs of the county are as follows:

Arctic Spring, Bangor.
Chapman's Spring, Orrington.
Highland Spring, Holden Center.
Hillside Spring, Bangor.
Oak Grove Spring, Brewer.
Sparkling Spring, Orrington.

Arctic Spring.—The Arctic Spring is situated $1\frac{1}{2}$ miles north of Bangor, and the water is sold in Bangor. The flow is reported as 8 gallons a minute and the temperature 44° . The hardness is 60 parts per million.

Chapman's Spring.—About one-quarter mile north of East Orrington is another spring the water of which is sold in Brewer. No information regarding it has been received.

Highland Spring.—The Highland Spring is situated on a hillside in the town of Holden, 5 miles east of Brewer. It is owned by Mr. C. B. Robinson, but is leased to Mr. A. H. Farrington. The water is said by the owners to issue from a crevice in the rock, and the spring is protected by a small house built over it. The water is bottled and shipped under the name "Highland Spring water." The analysis given in the table shows it to contain 16 parts per million of total solids. Owing to a misprint in the circular issued by the owners there are several errors in the composition reported. This water has been used in Bangor for sixteen years. The price of a 3-gallon bottle is 12 cents. This spring should not be confused with the Highland Mineral Spring in the city of Lewiston.

Oak Grove Spring.—The Oak Grove Spring is owned by Miss Jennie Farrington, of Brewer. It is situated on the eastern bank of Penobscot River, about one-half mile above the village of Brewer. The water issues from a steep slope of bowlder clay about 20 feet above the ordinary river level. In its exact geologic occurrence it issues from a bed of gravelly bowlder clay and is said to come from a vertical crack one-eighth of an inch in width in the ledge below this deposit. No houses are situated within 500 feet of the spring. The fields above

the spring are cultivated with grain, potatoes, etc. There seems to be little opportunity for pollution of the water, and it is probably perfectly safe for drinking. A small spring house has been built over the spring and the water is hauled to Bangor, where it is sold. It is colorless, odorless, and tasteless. The flow is about $1\frac{1}{2}$ gallons a minute and its measured temperature is 48° . The water sells at 12 cents a 3-gallon bottle. The spring has been operated for five years by the present management, but was run several years earlier by other parties. The water is highly appreciated by the people of Bangor.

In 1906, in connection with cooperative work on mineral waters by the United States Geological Survey and the Bureau of Chemistry in the Department of Agriculture, a complete analysis of this water was made. The various constituents found are as follows:

Analysis of water from Oak Grove Spring.

[W. W. Skinner, analyst.]

Gases (cubic centimeters per 1,000 grams at 0° C. and 760 mm. pressure):

Carbon dioxide (CO_2), free.....	9.00
Carbon dioxide (CO_2), set free from bicarbonates on evaporating to dryness.....	13.40

Parts per million, by weight.

Phosphoric acid radicle (PO_4).....	None.
Metaboric acid radicle (BO_2).....	None.
Arsenic acid radicle (AsO_4).....	None.
Silica (SiO_2).....	15.50
Sulphuric acid radicle (SO_4).....	4.94
Bicarbonic acid radicle (HCO_3).....	73.03
Nitric acid radicle (NO_3).....	5.30
Nitrous acid radicle (NO_2).....	Faint traces.
Chlorine (Cl).....	5.60
Bromine (Br).....	None.
Iodine (I).....	None.
Iron and aluminum (Fe and Al).....	.250
Manganese (Mn).....	None.
Calcium (Ca).....	18.58
Magnesium (Mg).....	3.50
Potassium (K).....	1.10
Sodium (Na).....	6.95
Lithium (Li).....	None.
Ammonium (NH_4).....	Traces.
Oxygen to form Fe_2O_3 and Al_2O_3	.100

135.850

Free ammonia.....	Traces.
Albuminoid ammonia.....	Traces.
Nitrogen as nitrates.....	1.20
Nitrogen as nitrites.....	Faint traces.
Oxygen consumed.....	4.00

A good recommendation for this water is that a Bangor photographer uses it entirely for his photographic work in preference to all other water.

Sparkling Spring, Orrington.—The Sparkling Spring is situated in the town of Orrington, about $1\frac{1}{2}$ miles from the Brewer line and one-half mile east of Penobscot River. It consists of a hole dug 6 to 10 feet deep in a hollow beside a little brook flowing over a gravel terrace. The water is reported to issue from three cracks in the ledge below, and it is said by the owners that a pole can be stuck down 10 feet in one of these cracks. This statement has not been verified. The water is sold in bottles in Bangor at the rate of 12 cents a 3-gallon bottle. The analysis shows 194 parts per million of total solids, distributed as in analysis No. 268, recalculated from the company's advertisement. "There is considerable free carbon dioxide in solution." The spring is owned by Mr. Albert G. Dole and is leased by Mr. E. H. Homestead.

PUBLIC SUPPLIES.

The public water supplies of Penobscot County are taken entirely from surface sources. The city of Bangor and the villages of Brewer, Veazie, Orono, Oldtown, and Milford use water taken directly from Penobscot River. The villages of Newport and Dexter obtain water from lakes near by. There are no well or spring supplies of any consequence.

PREDICTIONS AND RECOMMENDATIONS.

The most important water question in Penobscot County arises in connection with the public supply of Bangor and several surrounding towns. These now obtain their supply entirely from Penobscot River. This water is badly polluted by sewage and manufacturing wastes from towns farther up the river, and is therefore dangerous to the public health. The people of Bangor realize this and many of them have been agitating for a safer source of supply. In 1906 the late Freeman C. Coffin, of Boston, was employed by the city council to make a thorough investigation of the Bangor water problem, for the purpose of deciding on the best source for a new supply. In his report^a Mr. Coffin suggested four possible sources, as follows: (1) Ground-water supply; (2) Phillips Lake; (3) Felts and Eaton brooks; (4) Cold Stream Pond.

All the sources were found to be of excellent quality, but no definite decision was made between them. In regard to the ground-water supply, which was seriously discussed, two sources were considered, one in the broad flats west of Penobscot River and south of Pushaw Pond, the other east of Penobscot River and opposite the

^a Bangor Daily Commercial, March 13, 1906.

pumping station. Either of the sources ought to yield a satisfactory supply, the chief doubt being in regard to the amount of water which can be obtained. The surface water supplies mentioned above seemed to be of equal worth, but perhaps more expensive.

It may be some time before a pure water system is installed. Meanwhile it is desirable that as many individuals and companies as can afford it should drill wells for their own private supplies. So far as known, there have been no failures in deep wells within the city, and the deeper such wells are drilled the better and larger the supplies seem to have become. For that reason it is advised that well drilling be continued at least until the supply shows signs of diminution. Elsewhere in southern Penobscot County the conditions are very similar as regards the kind of rock, and there is no reason why wells 100 to 400 feet deep should not be just as successful as in the vicinity of Bangor.

SAGADAHOC COUNTY.

GENERAL DESCRIPTION.

Sagadahoc County is the smallest county in Maine. It is situated on the eastern border of Casco Bay and extends a few miles inland, having a length from north to south of 32 miles and an extreme width from east to west of 17 miles. Its area is only 259 square miles. The population of this county according to the census of 1900 was 20,330. Bath, the largest city, had a population of 11,527, more than one-half of the population of the county. Kennebec River flows from north to south across the center of the county and follows the eastern border for a short distance north of Bath. In Merrymeeting Bay it is joined by Androscoggin River, which separates this county from Cumberland. South of Bath, Sagadahoc County is cut up by many indentations of the sea and enlargements of the river. The altitude ranges from sea level to nearly 500 feet. The principal transportation line is the main line of the Maine Central Railroad, which extends from Brunswick along the west bank of Kennebec River, a branch of the same railroad which runs eastward beyond Bath, and a second branch which extends northwestward along the eastern border of Androscoggin River to Lewiston in Androscoggin County.

A map of Sagadahoc County showing distribution of deep wells, important springs, and communities having public supplies forms Pl. XX.

UNDERGROUND WATERS.

RELATION TO ROCKS AND SURFACE DEPOSITS.

Distribution of rock types.—The rocks of Sagadahoc County must all be grouped as complex, which consists of granites, gneisses, slates, schists, and diorites, so rapidly alternating with one another that

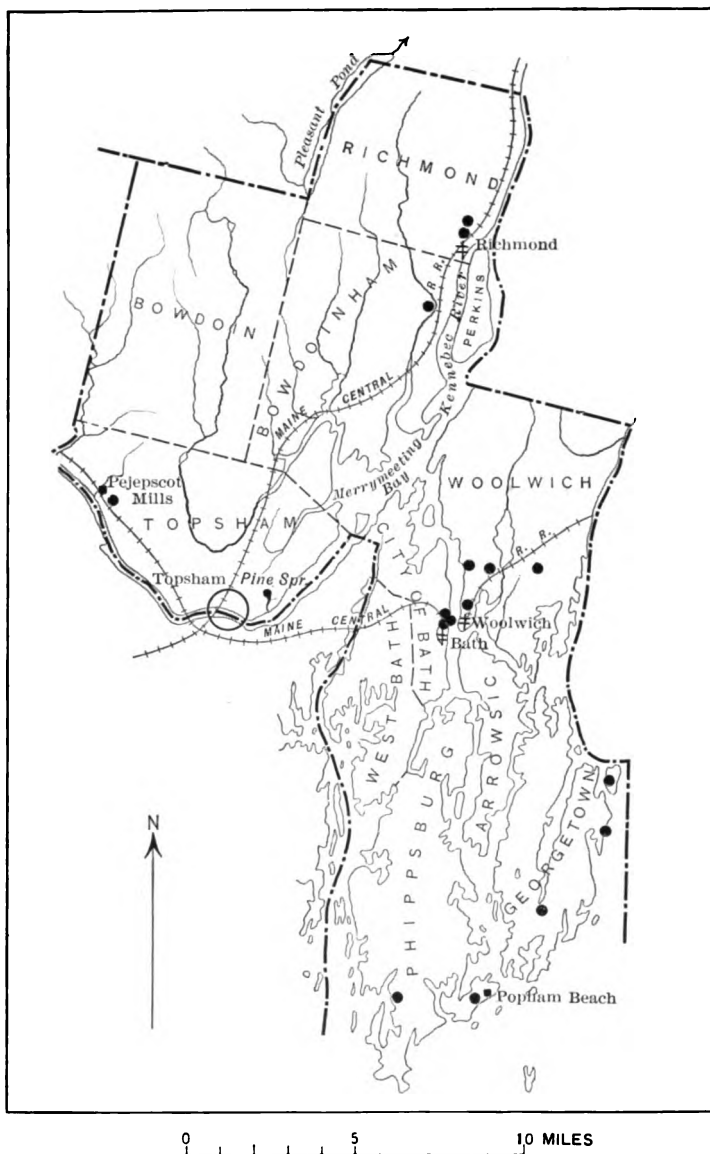
they can not be differentiated on any map. So far as observed in the field, the western portion of the county seems to be more gneissic and granitic than the eastern part, which is more schistose. The irregular proportions of the different rocks seem to have some effect on the quality of the water in various parts of this county and in adjacent counties.

Surface deposits.—The surface deposits of Sagadahoc County are not as thick as those in most other counties in Maine, owing largely to the fact that the county is cut up by many indentations of the sea and much opportunity has been given for the removal of the deposits by erosion. Along Kennebec River, up many of the small side valleys, and in a few sheltered places along the coast are small areas of clay, some of them 100 feet above sea level. These may be underlain by gravel. They are of considerable extent in the county and are overlain in many places by sand and gravel. Overlying the bed rock, as elsewhere in the State, is a thin coating of till, which in extreme cases is 20 feet or more in thickness. Borings in the valley of Androscoggin River in Topsham show that there the bed-rock floor of the valley is at least 155 feet below sea level, indicating a deep filling of gravel and an old gorge extending some distance back into the State.

WELLS.

GENERAL DESCRIPTION.

Only about 20 wells are known to have been drilled in Sagadahoc County. These are widely distributed, but are most numerous in Bath and Woolwich. They are mostly 6 inches in size, but a few 4-inch wells were sunk years ago. In depth they range from 40 to 335 feet, the deepest well in the county being that of the Pejepscot Paper Company, at Pejepscot Mills. An interesting fact is that although this well obtains only a small quantity of water a 40-foot well drilled for the same company a few feet distant obtained an inexhaustible supply, showing that the conditions are very uncertain. So far as can be learned from a study of the wells and records, it would not seem advisable to drill to great depths in this county. The limit should probably be about 200 feet. If a well reaches that depth without obtaining a sufficient supply the most economical procedure will be to drill a second well a short distance away. In the city of Bath most of the wells which were drilled years ago have been abandoned owing to the installation of a good city water supply. The abandonment has not been due in every case to the quality of the wells or the water. It can be stated, however, that the supplies in this county are not as good as in many counties of the State, and it is probable that not more than half the wells which have been drilled.



- Successful well over 50 feet in depth
- ⦿ Important spring
- † Community having public supply from surface sources
- Community having public supply from wells
- Other important towns

MAP OF SAGADAHOC COUNTY.

Showing distribution of deep wells, important springs, and communities having public water supplies.

are in use at present. Four field assays (Nos. 150, 151, 107, and 199) and one laboratory analysis (No. 152) are given in the table. One mineral spring has been analyzed (Nos. 269-270a).

DETAILED DESCRIPTIONS.

Bath.—The city of Bath has an excellent water supply, piped under Kennebec River from Nequasset Pond, in Woolwich. For this reason no drilled wells have recently been sunk in the city. Some drilling was done years ago, mostly between 1883 and 1895. Eight or more wells were sunk to depths of 50 to 100 feet, and the yield ranged from 2 to 30 gallons a minute. Some of the water was used for boilers, but most of it was for ordinary domestic purposes. A few wells are still in use. The C. A. Hooker well is 100 feet deep and the water will rise to the surface at times. A considerable number of people in Bath use shallow dug wells. Many of them are in poor locations where they might easily be contaminated by surface drainage. It is advised that all such wells be abandoned. Two field assays of waters from Bath have been made (Nos. 150 and 151).

Woolwich.—Next to Bath, Woolwich has the greatest number of wells in the county. Most of these are about 100 feet in depth. They yield several gallons of water a minute and seem to be fairly satisfactory as sources of supply. A laboratory analysis of water from one of them is given in the appended table (No. 152).

Georgetown.—On McMahan's Island a well of the Sheepscot Land Company was drilled to a depth of 246½ feet and obtained a good supply of water. At Five Islands Mr. George E. Hughes sunk a well to 242 feet. This is pumped by an electric motor and seems to be satisfactory. No other drilled wells are known in Georgetown.

Phippsburg.—Only one drilled well is known to have been sunk in the town of Phippsburg. This is a 96-foot well at Fort Popham, but no data regarding it have been received. Most of the wells in town are dug from 6 to 30 feet. At Popham Beach many driven wells have been sunk, getting fresh water from 6 to 15 feet below the surface, in sand. Below that depth salt water is encountered. The level of fresh water in these wells rises with the tide. Among the sand dunes are a number of small ponds, which indicate the level of water in the dunes. At Popham Beach several years ago a boring was made to a depth of 962 feet for coal, but without success.

Topsham.—The village of Topsham has combined with Brunswick in the Brunswick and Topsham Water District to install a supply of water from driven wells situated on the flood plain of Androscoggin River. The supply is so excellent that wells are unnecessary in these villages. At Pejepscot Mills a well 335 feet in depth gave only enough water for two families. A well was later drilled near by to a depth of 40 feet and obtained plenty of water. This is an example

of the extreme irregularity in the occurrence of rock water in this part of Maine. The formation here is mostly gneiss. In case any individuals or private companies in the village of Topsham desire water from wells in order to save water bills, it is probable that supplies can be obtained with success equal to that at Lisbon and Bath, a few miles to the northwest and east, respectively, of Topsham. The Pine Spring is situated in this town.

Bowdoinham.—The only drilled well known in Bowdoinham was sunk for Mrs. George L. Hinckley to a depth of 124 feet. This seems to have been a good well, but is not used on account of a broken pump. A dug well 40 feet in depth, 35 feet of which is in gravel and 5 feet in ledge, supplies 20 families. The rest of the wells here are less than 40 feet in depth. Two field assays (Nos. 107 and 109) have been made of well waters in this town.

Richmond.—A number of drilled wells have been sunk in Richmond in the past, but most of them are less than 50 feet in depth. One well 100 feet and one 65 feet deep are reported. Most wells in the village are abandoned, however, as there is a public supply from Kennebec River.

Other towns.—In the towns of Bowdoin, West Bath, and Arrowsic no drilled wells are known to have been sunk. While conditions are not as favorable as they are in Kennebec County, they seem to be better than in Lincoln County, and it is probable that drilling will be successful if the owner is willing to take the risk of possibly having to sink 2 wells before getting water.

SPRINGS.

General statement.—Springs are not especially abundant in Sagadahoc County, but some excellent ones are known. At Pejepscot Mills, in Topsham, the paper company owns an excellent spring which issues from sand and gravel in the bank of the river. The water is fine and cold and the rate of flow never varies. It is in such a situation that there seems to be no chance of pollution, and the water is highly prized by the people at the mill and by the inhabitants of the small village. A little spring house has been built and the water is pumped by means of a hand pump. One commercial spring is situated in the county.

Pine Spring.—As has been said, the Pine Spring is situated in the town of Topsham, 2 miles east of the village. It is owned by the Pine Spring Water Company, of Brunswick. The spring is situated in a small ravine in a sand plain. It is entirely surrounded by woods and as the only house in the vicinity is 500 feet distant, on the opposite side of the ravine, there is no chance for the water to become polluted. The water is colorless, odorless, and tasteless. The flow is 5 gallons

a. minute and the measured temperature is 44°. The water is sold as "Pine Spring water" and is bottled for ginger ale and "soda." It is not called a mineral water. A crate of six half-gallon bottles retails for \$1.50. Formerly a spring house was built over the spring, but it is now in disrepair. Such a house is unnecessary, as the spring is situated far from all buildings. The analysis of the water is given in the table (No. 269), having been recalculated from the analysis published by the company. Another analysis of the water made by W. W. Skinner, of the Bureau of Chemistry, United States Department of Agriculture, in connection with cooperative work on mineral waters conducted by the Geological Survey and the Bureau of Chemistry, is as follows:

Analysis of Pine Spring mineral water.

[W. W. Skinner, analyst.]

Gases (number of cubic centimeters per 1,000 grams at 0° C. and 760 mm. pressure):

Carbon dioxide (CO ₂), free.....	8.2
Carbon dioxide (CO ₂), set free from bicarbonates on evaporating to dryness.....	2.4
	Parts per million by weight.
Phosphoric acid radicle (PO ₄).....	None.
Metaboric acid radicle (BO ₂).....	None.
Arsenic acid radicle (AsO ₄).....	None.
Silica (SiO ₂).....	7.4
Sulphuric acid radicle (SO ₄).....	1.05
Bicarbonic acid radicle (HCO ₃).....	12.86
Nitric acid radicle (NO ₃).....	None.
Nitrous acid radicle (NO ₂).....	Faint traces.
Chlorine (Cl).....	4.20
Bromine (Br).....	None.
Iodine (I).....	None.
Iron and aluminum (Fe & Al).....	.32
Manganese (Mn).....	None.
Calcium (Ca).....	2.14
Magnesium (Mg).....	.79
Potassium (K).....	.60
Sodium (Na).....	3.49
Lithium (Li).....	None.
Ammonium (NH ₄).....	.026
Oxygen to form Fe ₂ O ₃ and Al ₂ O ₃	
	32.876
Free ammonia.....	.025
Albuminoid ammonia.....	.005
Nitrogen as nitrates.....	Traces
Nitrogen as nitrites.....	Faint traces.
Oxygen consumed.....	6.00

PUBLIC SUPPLIES.

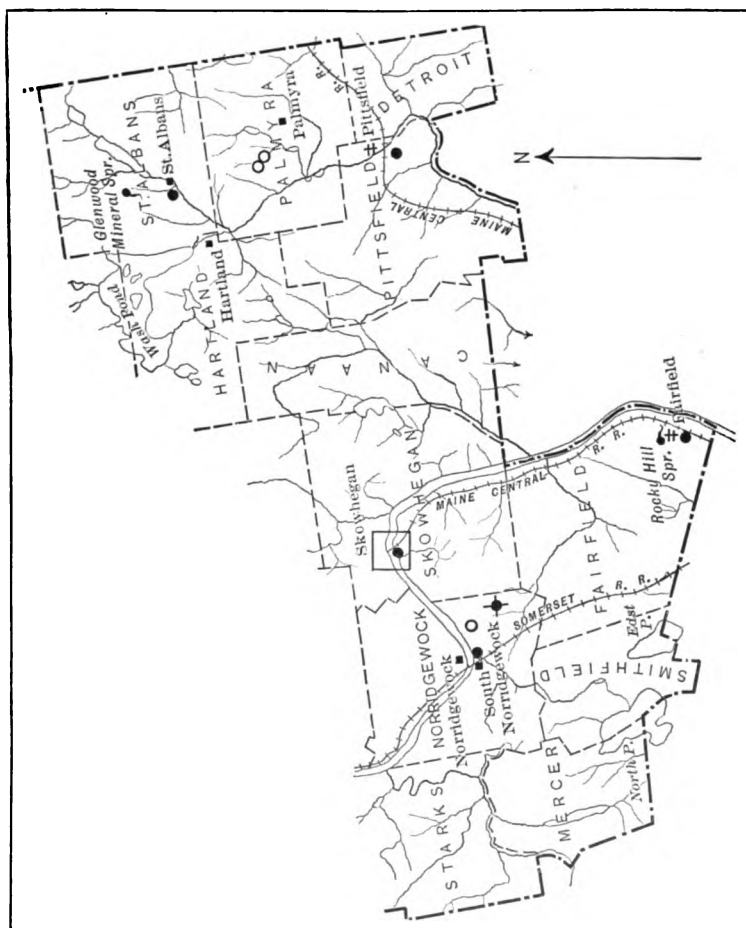
The city of Bath and the village of Richmond are supplied with water from surface sources, the former from Kennebec River and the latter from Nequasset Pond. Formerly the Bath supply was taken from 83 wells driven in sand, the average depth of which was about 20 feet. These wells were abandoned for the present supply. The village of Topsham has combined with Brunswick to obtain a system of water supply from driven wells on the flood plain of Androscoggin River, a short distance below the villages. This supply is described in connection with Cumberland County.

SOUTHERN SOMERSET COUNTY.**GENERAL DESCRIPTION.**

Somerset County lies somewhat west of central Maine and extends north and south about half the length of the State, a distance of about 140 miles. The maximum breadth of the county is 45 miles and its area is 3,831 square miles. In this report only the southern part of the county is included. The population of the whole county according to the census of 1900 was 33,849. The largest town is Skowhegan, with a population of 4,266. The county is rather mountainous, its altitude ranging from 150 feet above the sea along Kennebec River to 3,600 feet at the summit of Mount Bigelow, but the highest point in the area here discussed is probably not over 2,000 feet high. Kennebec River is the principal stream, and flows through the center of the county in a southerly direction, except in the vicinity of Skowhegan, where it makes a marked bend. There are no important tributaries to the river in this part of the county, although Sandy River enters from the west in the vicinity of Madison, and Sebasticook River rises in the eastern part of the county and flows southward. Scattered throughout the county are a great many large and small lakes, of which Moose Pond is the largest within the area covered by this report. The only lines of transportation are the Maine Central Railroad, which runs southward from Skowhegan along the west bank of Kennebec River, and the Somerset Railway, which runs northward from Oakland through the center of the county to Moosehead Lake, outside the limits of the area here considered. A map showing the distribution of deep wells, important springs, and communities having public supplies forms Pl. XXI.

UNDERGROUND WATERS.**RELATION TO ROCKS AND SURFACE DEPOSITS.**

Distribution of rock types.—The predominant rock formation of Somerset County is slate, and the whole northern part of the county is formed of this rock, with three important exceptions. These are



- Successful well over 50 feet in depth
- Unsuccessful well over 50 feet in depth
- ✕ Flowing well
- ⊙ Important spring
- ✕ Community having public supply from surface sources
- ⊠ Community having public supply from springs
- Other important towns

MAP OF SOUTHERN SOMERSET COUNTY.

Showing distribution of deep wells, important springs, and communities having public water supplies.

areas of granite. The first lies just west of Hartland and St. Albans and covers the southern part of Harmon, the western part of Hartland, the northeast corner of Cornville, and the southwest corner of Athens. The second granite area lies in the extreme southwest corner of the county and covers nearly the whole of Mercer, the portion of Norridgewock southeast of the village, and the west corner of Smithfield. The third granite area extends from Embden Pond, in Embden, northwestward beyond the limits of the area included in this report, and covers the northern part of New Portland, the northwestern part of Embden, the western edge of Concord, and probably the whole of Lexington and Highland plantations. Moderate amounts of water are found in granite, but the supplies are irregularly distributed. The granite is quarried in the vicinity of South Norridgewock.

The slate of this part of Somerset County is typical of the slate making up a large part of central Maine. It is a very fine-grained drab to black slate and splits parallel with the stratification. The strike is in general about N. 60° E. and the dip is as a rule nearly vertical, although in some places it is inclined. Locally this slate is slightly calcareous. Considerable water is found in this rock.

Surface deposits.—Along Kennebec River and in other sections where the land is rather low the surface is covered with sand and gravel and some clay, which form flat plains extending backward from the river in places for a mile or more. These plains are well developed in the vicinity of Skowhegan. One of these broad gravel-filled valleys lies between Norridgewock and North Fairfield. In these deposits good water is abundant and issues in the form of springs around the sides of the plains. The county contains also irregular gravel deposits. On the uplands the surface consists mostly of boulder clay, which ranges from a few inches to 20 feet or more in thickness. In some of the mountain regions the surface is nearly bare of drift.

WELLS.

GENERAL DESCRIPTION.

Types of wells used.—The prevailing type of well in Somerset County is the old-fashioned open well, such as is common throughout the State. These wells are, as a rule, sunk in boulder clay and gravel, although some of them are blasted a few feet into the rock. They range in depth from 5 to 40 feet. Generally they are successful in times of abundant rainfall, but are likely to run dry in summer.

Drilled wells.—Only about a dozen drilled wells have been sunk in Somerset County. In diameter they vary from 5 to 8 inches, but 6 inches is the prevailing size. The depth ranges from 26 to 157 feet, the most common depth being about 80 feet. They strike rock at 1 to 50 feet below the surface, and the greatest supply of water may

be found anywhere between the top and the bottom of the well. So far as known all the drilled wells have been sunk in slate, but there is no reason why they should not be successful in granite, as they are elsewhere in Maine. In one well the water rises to the surface of the ground.

Quality of water.—As few analyses have been made of waters from wells in Somerset County, not a very good idea can be given of the quality of water here. The total solids found in a well which was dug in drift and blasted in the underlying rock were 408 parts per million, and the hardness was 188. The amount of total solids in a drilled well was 56, and the hardness was 35. Another drilled well, 26 feet in depth, in slate and situated high up on a hillside, contained 29 parts of carbonates, a trace of sulphates, and 3.5 parts of chlorine. The details of these analyses are given in the table (Nos. 108 to 110). A good idea of the character of water which may be found in slate in this part of Maine may be had by consulting the analyses given in the table in connection with western Penobscot and northern Kennebec counties, on pages 78–79. The analyses of waters in granite in other parts of Maine are given on page 77. Analyses of several mineral springs are also given in the table (Nos. 271 to 273).

Quantity of water.—In general in Somerset County there seems to be plenty of water in the slates. Of the dozen wells drilled four have been failures, but three of these were situated on a barren hilltop where there was little soil and where there would seem to be little probability of finding water. The other well reported only a small fraction of a gallon per minute. One well was abandoned on account of poor water, and several have not been used since waterworks were installed in their respective towns. As the rock of Somerset County, with the exception of that in the granite areas, is similar to that of southern Penobscot County, where water is abundant, good supplies may also be expected in Somerset County.

Flowing wells.—A 25-foot well drilled on a slate hillside in the eastern part of Norridgewock obtained water which overflows the surface except in times of dry weather. With this exception no flowing wells are known in the county.

DETAILED DESCRIPTIONS.

Skowhegan.—Skowhegan, the county seat and largest town in Somerset County; is largely supplied with water by several aqueduct companies that obtain water from springs situated on the slopes of a sand plain bordering the village. The supplies are believed to be very good at present, but care should be taken to prevent their contamination by surface drainage. A full description of the public supplies of Skowhegan is given under the appropriate heading (pp. 209–210). The only drilled well in the village was sunk more than twenty years

ago for Mr. Levi P. Weston, on an island in the middle of the river. This well was pumped by a windmill, but was abandoned when the city waterworks were installed in 1888. On the sand plains surrounding the town there are a number of driven wells which seem to obtain adequate supplies of good water, and similar supplies may be obtained almost anywhere on the sand plains along Kennebec River.

Norridgewock.—On the sand plain south of the river in Norridgewock a large amount of water can be obtained by driven wells 10 or 15 feet in depth. The wells in the village are shallow. On the highlands east of the village of South Norridgewock are two drilled wells. One of these is 77 feet in depth and probably contains water, but has not been used because the owner had no deep-well pump. The other drilled well is situated in the eastern part of the town. It is only 26 feet in depth and overflows except in dry weather. It is siphoned down the hill to a farmhouse on the slope below and supplies water for domestic and farm purposes. It would seem that siphons might be more widely used in Maine. A field assay made of the water in this well is given in the table (No. 108).

Fairfield.—The village of Fairfield forms a part of the Kennebec water district, which obtains water from China Lake. In Fairfield an 8-inch well was drilled in 1884 to a depth of 91 feet. It is still used, and the water seems to be of good quality. As this town lies in the slate area in which abundant water supplies are found in neighboring parts of Penobscot County, it would seem that equally successful wells might be obtained here. The Rocky Hill Spring is situated in this town.

Pittsfield.—Pittsfield is supplied from the Sebasticook River. The water is reported as rather poor. In the village are a great many dug wells, 12 to 50 feet in depth, which are somewhat suspicious, as they are subject to contamination from surface drainage. One spring is situated near a number of houses and is probably not safe. Two or more drilled wells have been sunk in this village to a depth of less than 50 feet. The water is only of fair quality and is called hard. It is probable that more water could be obtained by sinking deeper, and it may be of better quality, although this can not be stated with certainty. An open well for Dr. F. J. Taylor was dug 20 feet and blasted 6 feet. The water has a fine taste and never gives out. A field assay of this water is given in the table (No. 110). A well drilled 47 feet for Mr. W. R. Hunnewell is reported to have a hardness of 35 parts (No. 109) while that of the Taylor well is 188. The total solids of the former were 56 and of the latter 408. In the Taylor well 48 parts of chlorine per million were found.

Palmyra.—Several drilled wells in Palmyra have attained fair success; several others, however, have not. An example of unsuccessful drilling is found on the estate of Mr. Perry Furbush, whose farm is

situated on top of a hill where the rock reaches the surface. Three wells were sunk. The first was dug and blasted 43 feet; then a horizontal gallery was run at right angles to the strike of the slate for a distance of 24 feet, but no water was found. This well was then drilled to 157 feet from the surface, when the tools became stuck and work was stopped. No water was found. Well No. 2 was drilled 80 feet through ledge and now supplies 20 to 30 gallons of water a day, summer and winter. Well No. 3 was also drilled 80 feet in ledge. The tools stuck at 80 feet, and the well had to be abandoned. This well was situated only 130 feet from the first. By pumping it dry every four hours 125 gallons of water a day could be obtained, which was not enough. As all the wells on this estate have proved to be practically failures, a spring some distance away on the hillside is used for watering the cattle. This spring is reported to issue from a vertical crack on a rotten seam parallel with the bedding of the slate. In other parts of town several drilled wells are supposed to have attained greater success, but these were not visited.

St. Albans.—At least one well is known to have been drilled in the town of St. Albans. The depth is reported to be 49 feet, and the yield is only a fraction of a gallon a minute. Deeper drilling in this town might meet with greater success in both the granite and the slate areas. The Glenwood Mineral Spring is situated in this town.

Hartland.—One or more wells less than 50 feet in depth have been drilled in the town of Hartland. The water was poor and they are not used. It would seem that by sinking to a greater depth water ought to be obtained in both the granite and the slate areas.

Madison, Anson, and Solon.—These three towns, although lying a little south of the northern extremity of the area considered in this report, have not been studied. They will be included in the report on the underground waters of northern Maine.

Other towns.—Other towns in this area obtain supplies entirely from dug wells and from springs. Where the wells are favorably situated the conditions are supposed to be good. In many places springs are of good quality and are much better and cheaper than wells.

SPRINGS.

General statement.—As stated above, springs are very abundant in Somerset County and are used for both public and private supplies, especially along Kennebec River. North of Madison several town supplies come from this source. Skowhegan and Fairfield also have spring supplies in part. Three mineral springs reporting sales are situated within the limits of Somerset County. These are the Glenwood Spring at St. Albans, the Pine Grove Spring near Pittsfield, and the Rocky Hill Spring at Fairfield.

Glenwood Spring.—In the town of St. Albans, about 2 miles north from the post-office, is the Glenwood Spring. The water is reported by the owner, Mr. C. A. Moulton, to issue from sand with a volume of 30 gallons a minute. It has no color, odor, or taste, and the temperature is said to be 48°. The water is shipped for table and medicinal use. An analysis, reported by the owner, has been recalculated into ions and parts per million and is given in the table (No. 272). The total solids amount to 67 parts. The following analysis, which gives the full composition of the water, was made by W. W. Skinner, of the Bureau of Chemistry, United States Department of Agriculture, in connection with cooperative work on mineral waters conducted by the Geological Survey and the Bureau of Chemistry.

Analysis of water from Glenwood Mineral Spring.

[W. W. Skinner, analyst.]

Gases (cubic centimeters per 1,000 grams at 0° C. and 760 mm. pressure):

Carbon dioxide (CO₂), free..... 7.30

Carbon dioxide (CO₂), set free from bicarbonates on evaporating to dryness..... 10.00

Parts per
million
by weight.

Phosphoric acid radicle (PO₄)..... None.

Metaboric acid radicle (BO₂)..... None.

Arsenic acid radicle (AsO₄)..... None.

Silica (SiO₂)..... 11.00

Sulphuric acid radicle (SO₄)..... 3.62

Bicarbonic acid radicle (HCO₃)..... 54.71

Nitric acid radicle (NO₃)..... 1.55

Nitrous acid radicle (NO₂)..... None.

Chlorine (Cl)..... 1.80

Bromine (Br)..... None.

Iodine (I)..... None.

Iron and aluminum (Fe and Al)..... .35

Manganese (Mn)..... None.

Calcium (Ca)..... 13.01

Magnesium (Mg)..... 2.49

Potassium (K)..... .93

Sodium (Na)..... 3.92

Lithium (Li)..... None.

Ammonium (NH₄)..... .011

Oxygen to form Fe₂O₃ and Al₂O₃..... .150

93.541

Free ammonia..... .01

Albuminoid ammonia..... .01

Nitrogen as nitrates..... .35

Nitrogen as nitrites..... None.

Oxygen consumed..... 5.00

Pine Grove Spring.—About 5 miles southeast of Pittsfield is a spring known as the Pine Grove Spring. The flow is reported large, and the temperature is given as 48°. The water is sold in Pittsfield and vicinity.

Rocky Hill Spring.—The Rocky Hill Spring, owned by Mr. W. N. Osborne, is situated 1½ miles north of the village of Fairfield. The spring is said to flow 18 gallons an hour and to issue from slate. The flow diminishes somewhat in a severe drought. The temperature is reported as 46°. The water is colorless and tasteless. It is sold in Waterville and Fairfield. A sanitary analysis made in 1896 showed it to be of excellent quality. The mineral analysis, from the analysis advertised by the owner, is given in the table (No. 271). A more complete analysis was made by W. W. Skinner, of the Bureau of Chemistry, United States Department of Agriculture, in connection with cooperative work on mineral waters conducted by the Geological Survey and the Bureau of Chemistry. This is as follows:

Analysis of water from Rocky Hill Spring.

[W. W. Skinner, analyst.]

Gases (cubic centimeters per 1,000 grams at 0° C. and 760 mm. pressure):

Carbon dioxide (CO ₂ free),	7.20
Carbon dioxide (CO ₂), set free from bicarbonates on evaporating to dryness,	11.60
	Parts per million by weight.
Phosphoric acid radicle (PO ₄),	None.
Metaboric acid radicle (BO ₂),	None.
Arsenic acid radicle (AsO ₄),	None.
Silica (SiO ₂),	10.60
Sulphuric acid radicle (SO ₄),	3.66
Bicarbonic acid radicle (HCO ₃),	63.57
Nitric acid radicle (NO ₃),	2.20
Nitrous acid radicle (NO ₂),	None.
Chlorine (Cl),	2.80
Bromine (Br),	None.
Iodine (I),	None.
Iron and aluminum (Fe and Al),	.140
Manganese (Mn),	None.
Calcium (Ca),	13.29
Magnesium (Mg),	4.34
Potassium (K),	.85
Sodium (Na),	4.60
Lithium (Li),	None.
Ammonium (NH ₄),	Traces.
Oxygen to form Fe ₂ O ₃ and Al ₂ O ₃ ,	.060
	106.110
Free ammonia,	Traces.
Albuminoid ammonia,	Traces.
Nitrogen as nitrates,	.50
Nitrogen as nitrites,	None.
Oxygen consumed,	3.50

PUBLIC SUPPLIES.

Skowhegan.—About half the inhabitants of Skowhegan obtain water from what is known as the "city water" system. This system is, however, owned by the Skowhegan Water Company, which has a contract to provide the village with fire protection. The water comes from a ponded brook in a valley on the eastern edge of the village and is believed to be of fair quality. There are also four aqueduct systems drawing water from springs situated in ravines in the sand plains which surround the village. These are the West Aqueduct Company, the Coburn Aqueduct Company, the Skowhegan Aqueduct Company, and the Niel Aqueduct Company. All these supply the part of the village situated north of the river. On the south side of the river there are a number of private systems.

The springs of the West Aqueduct Company are two in number and issue from the base of a sand and gravel plain on the northern and western edges of town. The plain is underlain by clay. One of these springs is situated 300 feet from the nearest house built on the plain above; this is probably safe. The other spring is 50 feet or less below a stable on the edge of the plain; this spring would seem to be dangerous and ought to be abandoned. The water is collected in two tanks built over these springs and runs by gravity to the houses where it is used. Most of West Skowhegan gets water from this system. The water is called excellent by the users. This is the largest aqueduct system, and supplies about 150 families. A field assay of tap water is given in the table (No. 273).

The spring of the Coburn Aqueduct Company is situated within a few hundred feet of the West Aqueduct springs, in another ravine. This water is of excellent quality and appears to be safe. The system is reported to supply about 100 families.

The Skowhegan Aqueduct Company's system is smaller, deriving its supply from a well and a spring situated on the edge of the plain on North street. The well is a large dug well, probably 15 feet in depth, on top of the plain and not 50 feet distant from two houses. The water is in sand, on top of clay. The company is reported to have 36 takers. The spring is situated not 20 feet from a house and on the slope below it. This situation appears rather dangerous and it would be advisable to abandon the spring.

The Neil Aqueduct Company obtains its supply from an old brick-yard some distance down the ravine from the springs of the West Aqueduct Company.

All these supplies are gravity systems, and as the sources lie on the edge of the sand plain they can not reach the people living on the higher land. These families are supplied by "city water." Most of the patrons of the aqueduct water use spigots, which flow a

constant stream through a hole about one-twentieth of an inch in diameter through a glass tube. The rates are \$6 a year.

The first aqueduct line is reported to have been laid in this village as long ago as 1830.

Other towns.—A part of Fairfield has a spring supply. Pittsfield and the rest of Fairfield use surface water.

PREDICTIONS AND RECOMMENDATIONS.

In Somerset County the conditions for obtaining underground-water supplies seem to be fairly good, but as yet they have not been fully developed. In a few places, as in some of the villages, water is obtained from dug wells which are evidently polluted by surface drainage and are unsafe. Where there is any suspicion about the quality of the water the dug wells should be abandoned for the public supplies or drilled wells. The latter are suitable for use nearly everywhere and are in many places better than the public supplies. Some springs have been seen which should not be used, but as a rule the springs in the county are well situated and are safe for drinking.

WALDO COUNTY.

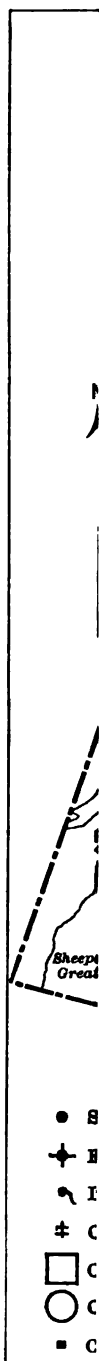
GENERAL DESCRIPTION.

Waldo County lies in southern Maine, just west of Penobscot River and Penobscot Bay. It is a small county, having a total extent north and south of only about 35 miles, and the same east and west. Its area is 748 square miles, and the population according to the census of 1900 was 24,185. Belfast, the principal town, contains 4,615 inhabitants. This county is moderately hilly and ranges in elevation from sea level to nearly 1,100 feet. It has no large streams except the Penobscot, on which it borders, but contains a few small lakes. Its transportation lines are the Maine Central Railroad, running northwestward from Belfast across the county, and the Bangor and Aroostook Railroad, which runs northward from Searsport. A map of Waldo County showing the distribution of deep wells, important springs, and communities having public supplies forms Pl. XXII.

UNDERGROUND WATERS.

RELATION TO ROCKS AND SURFACE DEPOSITS.

Distribution of rock types.—Probably about half of Waldo County is composed of slate. The area occupied by this rock lies northwest of a line drawn roughly from the southwest corner of the county northeastward to Penobscot River, on the border of Penobscot County. There is also a considerable patch of slate and slaty rocks southwest of Stockton Springs, which covers the greater part of the



towns of Searsport, Belfast, and Belmont and smaller parts of Searsmont and other towns. Islesboro is also mostly slate, although thin and unimportant bands of limestone are reported to cross this island.

The principal granite area in Waldo County lies in the southeastern part of Winterport, the eastern part of Frankfort, in Prospect, northern Searsport, and eastern Swanville. Parts of Swanville, the greater part of Waldo, smaller parts of Brooks, Morrell, western Searsmont, southeastern Montville, Liberty, and southeastern Palermo are underlain by a complex consisting mostly of granite, gneiss, diorite, schists, and other rocks. Another arm of the complex enters the southern edge of the county and covers the greater part of Lincolnville and Northport, but also includes part of Searsmont and probably a corner of Belmont.

As a rule the slate of Waldo County strikes in a northeast direction, and the cleavage has generally about the same trend. The slate is hard and compact and the dip is always high. A small part of eastern Waldo County has been studied thoroughly by the geologists of the United States Geological Survey, and the results have been published in the Penobscot Bay geologic folio.^a It is therefore possible to say with considerable certainty what kind of rocks are found in the various towns in this region. The distribution of these rocks will be described under the town headings.

Surface deposits.—The unconsolidated deposits forming the surface of Waldo County consist for the most part of boulder clay, which ranges in thickness from 1 to 20 feet or more, but is commonly thin. This boulder clay generally forms the surface on the hills where they do not consist of bare rock, but in the lowlands it is in many places overlain by various amounts of stratified sand and gravel, and here and there by clay. These deposits locally form flat plains, but are nowhere of great extent.

WELLS.

GENERAL DESCRIPTION.

Types of wells used.—The predominant type of wells in Waldo County is the open well. They vary in depth from 10 to more than 30 feet and are generally dug in gravel or boulder clay, although some of them are blasted in rock. These wells are generally successful in wet seasons, but in summer they usually dry up.

Drilled wells.—A greater number of wells have been drilled in Waldo County than in any other county on the Maine coast except Cumberland. There are more than a hundred such wells within the limits of the county. They are mostly 6-inch wells, but a few 7 inches in size are reported, and a number of wells are 8 inches at the top and 6 inches at the bottom. One well was 10 inches at the top and 8

^a Geologic Atlas U. S., folio 149, U. S. Geol. Survey, 1907.

inches at the bottom. In depth they run from 30 to 329 feet. Most of them have been successful, although a few have been abandoned owing to insufficient supply, and in one or two the quality of the water has not been up to the standard.

Quality of water.—The quality of water in Waldo County is generally good. In all, 14 analyses are known to have been made. Most of them are of slate waters, but a few analyses of water from other rocks have been made. The total solids reported range from 138 to 163 parts per million, and one well reports them as high as 234. The hardness runs from 85 to 152 parts, but is reported in only a few analyses. The carbonates range from none to 28, and the calcium from 8 to 47. Some reports of iron run as high as 10, but these are believed to be erroneous. A better idea of the quality of the water can be had from the table (Nos. 111 to 127, 153, and 154).

Quantity of water.—The quantity of water found in wells in Waldo County is extremely variable, depending on the situation, time of year, kind of rock, and other conditions. In some wells only a trace of water was found. In one of the wells situated at Cape Jellison the supply was 200 gallons a minute, according to the reports of the railroad company. Only a few failures have occurred in the county. In general the water seems to be best in slate. In the complex region indicated on the map (Pl. I) supplies will probably not be found to be quite as large as elsewhere.

Flowing wells.—Several flowing wells have been noted in Waldo County. Two of these are situated in the town of Islesboro and are deep drilled wells, probably deriving their head from near-by hilltops rising a few feet above the surface of the well. A similar well is reported at Searsport, but the hill from which its head is derived seems to be at a distance of several hundred feet. The flowing wells in slate of which these are examples are caused by water pressure due to the inclination of the joint cracks running from hills in the vicinity, and the flows are found where the intervening rocks are overlain by clay and hardpan, which close the joints at the surface.

DETAILED DESCRIPTIONS.

Belfast.—Belfast obtains its public supply from Little River, which enters the sea 2 miles south of the village. The water is poor, being taken from a very swampy reservoir near the mouth of the river. In summer it has a fishy odor. As far as health is concerned it is probably not dangerous, and if taken from a higher point on the same river and confined in a reservoir containing less vegetation the water would probably be satisfactory.

In the upper part of the village a few wells have been dug in clay and bowlder clay. These are situated near houses and are in danger of pollution from drainage. Some persons prefer the wells to the city

water, but the public supply is safer. One drilled well in town is 39 feet in depth, and the water is used for domestic purposes. The slate in this town is similar to the slate of Penobscot County and ought to give plenty of water, although its capacity has not yet been thoroughly tested by drilling.

Belmont.—The only drilled well in Belmont is that belonging to Mr. Horace Chenery. It is 187 feet deep, and slate was struck at 12 feet from the surface. The well was cased with 10-inch casing to rock, and 8-inch casing was then placed inside and the space between filled with cement, making it water-tight. The yield is reported as 19 gallons a minute, and the analysis (No. 111) records 138 parts per million of total solids.

Searsmont.—In Searsmont there are no drilled wells. The deepest well is dug 44 feet deep and supplies good water. A field assay (No. 201) shows 16 parts per million of carbonates. The public supply of Searsmont is obtained from springs. The village has a few driven wells, but none have been drilled.

Northport.—The town of Northport is underlain largely by a complex of slates and schists, with considerable granite and diorite and other injected igneous rocks. Northport Camp Ground is supplied by a public system from springs and a drilled well belonging to the Mountain Spring Water Company. The well is 168 feet deep, is situated on the hill in the upper part of the village, and supplies 27 gallons of water a minute. An analysis (No. 153) shows total solids amounting to 145 parts per million and a hardness of 87. Another well, 64 feet in depth, obtained a small amount of water. The total solids and the hardness are 234 and 126 parts per million, respectively. A full description of the deeper well is given under the heading "Public supplies" (p. 217).

Searsport.—Searsport is underlain mostly by slate and schist. There are, however, traces of other rocks in the town. The village until recently was supplied by two springs situated on the hillside 2 miles west of the village, but now buys its water from Stockton Springs, which obtains its supply from Halfmoon Pond.

The best drilled wells in Searsport are those of the Bangor and Aroostook Railroad (Northern Maine Seaport Railroad Company). One of these, situated at the terminal, is 329½ feet deep. This well yields 60 gallons of water a minute with a steam pump. A similar well at Kidders Point is 285 feet deep and yields 130 gallons a minute. The water is sold to supply steamships and is also used for running an electric plant.

In the village of Searsport there are several wells. Some of these are about 100 feet deep and give many gallons of water per minute. The well at the Searsport House is said to overflow the surface in wet weather. The quality of the water is very good. The common

constituents are reported in the analyses of the railroad wells (Nos. 118 and 123). As will be seen, the total solids range from 100 to 150. The water is excellent for drinking purposes, but it forms a small scale in locomotive boilers.

Stockton.—The village supply of Stockton Springs is taken from Halfmoon Pond. The railroad has a well at the "Y," one well directly east of the village, and two wells at Cape Jellison. These wells range in depth from 158 to 247 feet and yield from 10 to 200 gallons a minute. Of the wells at Cape Jellison one was drilled 158 feet, giving 12 gallons a minute, but the supply decreased; the other was sunk to 225 feet, and at that depth gave 200 gallons a minute. These wells are pumped by steam and electric pumps. Two analyses of water are given in the table (Nos. 112, 127). In both wells there is much iron, due to the rusting of the pipes, but the water is good. It is excellent for drinking, but some scale forms in boilers. There are several other drilled wells at Stockton Springs.

Prospect.—In the eastern part of the town of Prospect the Switzer Spring is situated. All wells in the town are shallow and none is known to have been drilled.

Frankfort.—Most of the wells in Frankfort are dug wells, but one or more drilled wells are reported. The water in the eastern part of town is mostly granite water; that in the western part is largely slate water. The wells in the western section will probably be somewhat the more successful.

Winterport.—Winterport has a public supply from West Branch of Lowes Brook. There are no drilled wells in the eastern part of the village, but in the western part there are several, the conditions for water being better in that section. The supplies are obtained in slate similar to that at Bangor.

Monroe.—At least one drilled well is situated in the town of Monroe. This is a 7-inch well 61 feet deep. The water contains some iron, but is used for domestic purposes and for stock.

Jackson.—Several drilled wells in Jackson are between 45 and 65 feet in depth. One of them is a 9-inch well. The water from all of them is used for domestic purposes and for stock.

Brooks.—The public supply of Brooks is taken from two springs in the village. A few people use dug wells, some of which have caused sickness in the past. There are a number of drilled wells in town, but no information regarding them is at hand. There ought to be plenty of water in slate at this place.

Thorndike.—Wells have been sunk in the town of Thorndike, but no data have been received regarding them. The conditions ought to be as good as in other towns in the vicinity which derive their water from the slate formation.

Troy.—In Troy most wells are blasted and drilled in rock. The depth ranges from 20 to 70 feet, and plenty of water is obtained for domestic and farm purposes. Most of the wells are of the ordinary size, but in 1876 one 8-inch well was sunk. Conditions in this vicinity are probably good.

Islesboro.—Drilled wells are practically the only kind used in southern Islesboro, and the island contains more of these than any other town in Maine. It is occupied as a summer resort by many wealthy people, who can afford the best type of wells, and more than 40 have been drilled. The depths range from 60 to 398 feet, the common depth being 60 to 120 feet. There is generally plenty of water, and some wells report more than 15 gallons a minute. The 149-foot well of the Islesboro Land and Improvement Company supplies a large summer hotel and sometimes 10 cottages, the yield being 8 gallons a minute. Only two or three failures are reported. The majority of wells lie south of Dark Harbor, but a few are situated farther north. There are several drilled wells at North Islesboro.

In quality the water of the Islesboro deep wells is uniformly good. It varies, however, from hard to soft. One analysis reports total solids as high as 145 parts per million and a hardness of 86. The chlorine in three other wells varies from 7 to 33, and the carbonates, where determined, run between 85 and 127 parts. There is generally a trace of sulphate, but no iron. (See analyses Nos. 113 to 116.)

The predominating rocks on Islesboro are a series of volcanic rocks and interstratified slates, tuffs, etc. There are, however, a few narrow bands of limestone extending in a general north-northeast direction, and just west of Meadow Pond in North Islesboro is a small patch of quartzite. Several small areas of greenstone are found in the southern part of the main island and on some of the smaller islands of the town. The limestone is probably responsible for the hard water which is sometimes reported. The drift on the island is generally very thin, but where it is thick enough some dug wells are used. The water in these is likely to be softer than in the drilled wells. Some of the dug wells can not be pumped dry. The drilled wells are, however, always best for drinking. One drilled well enters a hard, granitic-looking rock at 20 feet from the surface. This is called "granite" locally, but is probably only a more metamorphic portion of sandy slate.

Well drillers report that 75 per cent of the water on Islesboro is found on the western side of the ridge. A popular belief on the island is that the deep-well supplies come from the mountains on the mainland. This is not impossible, but calculation based on the amount of rain water falling annually on Islesboro, and an estimate of the amount which is probably absorbed by the surface deposits,

show that there is plenty of water to supply all the dug wells without having to postulate such a distant source.

A well on Bevidges Point obtained salt water at a depth of 220 feet. This well was filled with Portland cement to a depth of about 200 feet, and now the water is excellent. Mr. Edwin Bevidge, on the same point, also obtained salt water, but it was not salty enough to injure the well for domestic purposes.

SPRINGS.

General statement.—Springs are very numerous in Waldo County, and some are used for domestic supplies. At the town of Brooks the public supply is derived from springs, and in Searsport spring water has been used in the past for public supply. The principal commercial springs of the county are the Switzer Spring, in Prospect, and the Thorndike Mineral Spring, in Thorndike.

Switzer Spring.—The Switzer Spring, owned by the Switzer Water Company, of Bangor, is situated in the town of Prospect, half a mile northwest of Prospect Ferry. The water comes from a fissure in granite and flows through about 20 feet of gravel, from which it issues in a good-sized stream. The yield is reported in the company's circular as 150 gallons a minute. The flow is reported to be constant, and pumping by a windmill does not lower it. The temperature is reported as 44°.

The Switzer Spring water is mostly carbonated and used for soft drinks, but a small amount is bottled and shipped as spring water. The water is pumped to the bottling house 100 feet away. Some of the residences in the vicinity use this spring water for drinking.

Thorndike Mineral Spring.—Three miles east of Thorndike post-office is the Thorndike Mineral Spring, owned by Mr. Ross C. Higgins. The water seeps out of a hillside with a volume estimated by the owner as a gallon a minute. The water is very clear, but has a strong odor and taste of sulphur. It does not carry any sediment. A white sulphurous deposit is said to be formed on rocks above the spring. The water is used for drinking and for medicinal purposes and is sold. No analysis is reported.

PUBLIC SUPPLIES.

General statement.—Several villages and towns in Waldo County have public water supplies. Of these Belfast, Searsport, and Winterport use water from surface surfaces. Brooks and Searsmont have spring supplies, and Northport Camp Ground has a supply from a deep drilled well and a spring.

Brooks.—The village of Brooks has been supplied since 1900 by the Ames Spring and the Ginn Spring, which flow by gravity into a 10,000-gallon tank. The system is owned by the Consolidated Water Company of New Hampshire. The Ames Spring is about 75 feet at

the Ginn Spring 125 feet above the tank.' Forty-three families and business houses, constituting about three-fourths of the village, are supplied, and about 5,000 gallons of water are used daily. The town has 2 miles of 3-inch and 1-inch mains. The Ginn Spring is the larger of the two springs, varying in flow from 3 to 6 gallons a minute. The Ames Spring may flow 1 gallon a minute. There is plenty of water for all present needs. A sanitary analysis made in 1903 shows the water to contain 150 parts per million of total solids and to have a hardness of 113. The chlorine was normal, and nitrites and nitrates were absent.

Searsmont.—The water supply of the village of Searsmont has for over fifteen years consisted of a gravity system from a spring owned by D. B. Cobb & Son. The spring issues from bowlder clay in an open field. In use it gives a head which will raise the water 100 feet above the center of the village. The mains consist of about half a mile of 2-inch iron pipes. Ten families, or about half the village, use the water. The amount is more than sufficient for all immediate needs. The quality of the water appears to be first class, but it contains a little iron. There is a barn about 300 feet distant, along the hillside, but no trouble has been experienced with the water. As a precaution it would seem desirable to change to a spring higher on the hill. The boggy nature of the surface indicates that a spring could be obtained higher up.

Northport Camp Ground.—The village of East Northport, or Northport Camp Ground, has for nearly twenty years been supplied by gravity from a well and a spring owned by the Mountain Spring Water Company. The spring, situated $2\frac{1}{2}$ miles back on the mountain, is used the year round, and the well situated on the hill above the village is used as an additional supply during two months of the summer season. The well was first drilled to a depth of 95 feet, but it could be pumped dry, so drilling was continued. The rock is supposed to be schist, struck at 50 feet from the surface. At about 150 feet the drill dropped 18 inches and all the water was lost. The well was deepened to 168 feet and the water can now be lowered 30 feet by pumping. It has been pumped seventeen hours with no signs of exhaustion. There are about 200 takers and 500 taps, making about 95 per cent of the summer population who use the public supply. The village has no fire hydrants. In the height of the season 20,000 gallons of water are used in twenty-four hours. The mains are reported to be 12 miles in length. They are 6 inches and 2 inches in size.

PREDICTIONS AND RECOMMENDATIONS.

The improvement of the waterworks belonging to the town of Belfast is important. The village now obtains its supply from a rather poor reservoir near the mouth of Little River. The water has a disagreeable fishy odor and its use is at times very unpleasant. It is not

supposed to be detrimental to the public health, and in spite of its poor taste it is believed to be better than the water taken from dug wells in the heart of the village. In order to give entire satisfaction, however, the supply should be improved.

It is suggested that if a reservoir were built higher up on the same stream, and if care were taken to remove decaying vegetable matter and other organic materials from the reservoir and banks, the present trouble might be avoided. It is also possible that treatment with a minute quantity of copper sulphate, by a competent engineer, might improve the condition of the water.

Another recommendation to be made in respect to Waldo County is that a larger number of drilled wells be sunk. Many dug wells that do not give proper satisfaction might be replaced by drilled wells with probably good results, as the slates of Waldo County seem to contain plenty of water.

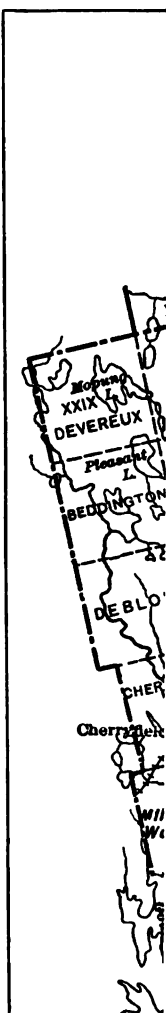
SOUTHERN WASHINGTON COUNTY.

GENERAL DESCRIPTION.

Washington County lies in the southeastern part of Maine, being bounded on the east by New Brunswick and on the south by the ocean. The length of this county is about 90 miles and its maximum breadth about 60 miles. The total area is 2,456 square miles, and the population according to the census of 1900 was 45,232. The largest city is Calais, with a population of 7,655, and the next largest is Eastport, which contains 5,311 inhabitants.

Washington County may be conveniently subdivided into three sections. The southernmost is a narrow strip along the coast, which contains a few small cities and towns. The central section, covering by far the greater part of the county, is an uninhabited wilderness. A few miles of the northern part of the county, near the Maine Central Railroad, also is somewhat settled and contains many farms. The area described includes the coast section and about half the wilderness section. The only railroad in the region covered by the report is the Washington County Railway, which crosses within a few miles of the coast, from Ellsworth, in Hancock County, to Calais and Eastport, on the eastern boundary of Washington County. Calais lies somewhat outside the area of this report as defined in the introduction, but it is included here in order to make a unit in discussion of the southern section of Washington County. Pl. XXIII is a map of southern Washington County showing the distribution of deep wells, important springs, and communities having public supplies.

This county is unusually well supplied with surface water, the principal rivers being the St. Croix, dividing Maine from New Brunswick, the Machias or Kowahskiscook, Pleasant River, and Narra-



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guagus River. Throughout the wilderness there are abundant lakes, some of them 5 to 10 miles in length. The county is fairly hilly away from the coast, but not so rough as the adjacent part of Hancock County.

UNDERGROUND WATERS.

RELATION TO ROCKS AND SURFACE DEPOSITS.

Distribution of rock types.—Probably one-third of the area considered in this county is underlain by granite. A band of this rock which has a width of 10 to 20 miles extends from the southwest corner of the county, in the vicinity of Millbridge, northeastward to the vicinity of Calais. Another granite area extends from Hancock County across the boundary a short distance into Washington County. The areas mapped as granite in Washington County include small areas of diorite, a rock somewhat similar to granite, but darker and more basic.

Between the two principal granite areas, occupying most of the region north of the Washington County Railway, between Cherryfield and Addison, is a large slate area. The region lying southeast of the railway, between Machias and Pembroke, consists to a large extent of slate, but includes also some volcanic rocks. Probably the most extensive of these lie in the extreme southeastern part of the State. Some unmetamorphosed siliceous shales occur in the southeastern portion of the county.

In the towns of Perry and Robbinston is an area known as the Perry Basin, which is composed of rocks of different types from those found elsewhere in Maine. These are mostly conglomerates, sandstones, and some lavas. The sedimentary rocks here contain fossils, and by these their age is known to be Devonian.

Surface deposits.—The surface deposits of Washington County differ greatly in character. In many parts of the county there are areas of several square miles which are made up almost entirely of plains and undulating deposits of gravel and sand, in places 100 feet or more in thickness. One of these areas, situated in the town of Columbia and vicinity, consists of a flat plain 250 feet above the sea and several miles in length. Underneath the gravel deposits and covering a large portion of the bed rock of the county is a thin coating of till. Small areas along the coast and near the mouth of the principal streams consist of clay.

WELLS.

GENERAL DESCRIPTION.

On account of the great abundance of good spring water in Washington County the proportion of wells is not great. Throughout the country districts the use of springs is probably fully as extensive

as that of dug wells. The known drilled wells exceeding 40 feet in depth number only 12. These are mostly situated in the extreme east corner of the county, but there is one drilled well on Roque Island and one at Jonesport. Three deep driven wells have been sunk at Columbia Falls.

Little is known of the quality of well water in Washington County. Two laboratory analyses (Nos. 158 and 191), however, are reported, and several field assays (Nos. 190, 192, 193, 157, and 159) have been made. Wells in sand and gravel were found to be low in mineral matter, but those in greenstone were high. For analyses of granite waters persons interested are referred to page 77, where they appear in connection with the descriptions of other counties. The table also contains several analyses and field assays of springs (Nos. 275 to 284), some of which are of great mineral purity.

DETAILED DESCRIPTIONS.

Calais.—The city of Calais has taken its public supply from St. Croix River. The water was poor, however, and it has recently been abandoned for a spring supply brought from St. Stephens, New Brunswick. The wells in the city are mostly shallow. Several drilled wells are not used. There is no reason, however, why plenty of good water may not be obtainable by drilled wells in that region, as good wells have been obtained in the same granite rocks across the river.

In the country districts of Calais springs are largely used. These generally emerge from till or sand; one spring, however, was seen issuing from a crack in diorite. Some wells in town are sunk in clay. The water in these is generally poor. In the vicinity of Red Beach there are many granite quarries. No water was seen in them, but its absence was probably due to the small amount of soil on the hills where the quarries are situated, as granite generally contains water. The only reports of the composition of water in Calais are given by a laboratory analysis and a field assay of water from a 44-foot bored well in sand and gravel (Nos. 190 and 191).

Eastport.—Eastport is underlain largely by basic volcanic rocks which were originally lava flows. The city obtains its public water supply from Boydens Lake, in the town of Perry. The one drilled well in town is owned by the Seacoast Canning Company. It is 408 feet in depth, drilled in the bottom of an old quarry in the basic lavas. The rock is very hard for a depth of 250 feet, and several drills were broken, but below that depth the formation is softer. Most of the water was obtained at 345 feet, but small amounts were found at other levels. At times the water overflows the bottom of the quarry. The water was lowered 28 feet when pumped with an ordinary steam pump, and the amount was found to be too small for use. In 1906

pipes were run down 225 feet and a deep-well pump was installed. An attempt was made to use a force pump, but the rock was found to have been so broken up by blasting in the quarry that the water was forced by the pump into the fissures of the rock instead of out of the mouth of the well. In a test with a 3½-horsepower gas engine the water was lowered 75 feet and 60 gallons a minute were obtained, but it is not believed that the well would yield that amount by continuous pumping. An analysis of this water given in the table (No. 158) shows 413 parts of total solids, 48 parts of silica, and 71 parts of sulphates. This analysis is interesting, as it is the only one available of water from greenstone in Maine.

A large part of the peninsula of Eastport is bare rock, but there is some clay and gravel. A section of a dug well on the outskirts of the city is as follows: Soil, 3 feet; gravel, 5 feet; blue clay, 20 feet.

Some wells situated 50 to 80 feet above tide on the borders of the village obtain plenty of water below the bed of clay. Several of these were abandoned because they contained salt water. At a time when it was desired to supply the city by underground water a 40-foot test well was driven for the waterworks. This well flows at the surface and is used by farmers in the vicinity. The water is somewhat salty.

Lubec.—Lubec has an excellent water supply from springs situated west of the village. This system is described on pages 224-225. In the village of Lubec there are three drilled wells, and at North Lubec there are three more. The latter were drilled for the Seacoast Canning Company and are used and pumped by a windmill. In Lubec a well 100 feet deep was sunk for a hotel owned by Mr. W. J. Mahlman. Water was obtained at 96 feet and was pumped by a windmill. It was good water, but as only 8 gallons a minute were obtained the well was abandoned when the city water was installed. The well of the Lubec Sardine Company was drilled 165 feet and scarcely any water was found.

The rocks at Lubec are slates intruded and metamorphosed by large masses of gabbro. West of the peninsula the drift is generally thick and there is some clay. The field assay of one 30-foot well in clay is given in the table (No. 166).

Perry.—All wells in the town of Perry are open wells. In most of those which are sunk in clay the water is "brackish." The town is reported to be abundantly supplied with springs which issue from volcanic rock, sandstone, and clay. The flow is reported as much as 20 gallons a minute in wet weather and a little less in dry weather. A single field assay of water from a dug well is given in the table (No. 202).

Pembroke.—The general depth of wells in Pembroke is 5 to 30 feet. They are all open wells and are mostly dug in till and gravel.

Machias.—The town of Machias uses Machias River water. There are few wells in the town, and all are open wells. Some of the shallower ones penetrate clay and obtain water in gravel at an average depth of about 20 feet. Many families near the village use spring supplies. Some of the springs flow as much as 5 gallons a minute.

Marshfield.—There are no drilled wells in the town of Marshfield, and water is obtained from dug wells and springs. An analysis has been made of one 21-foot well which penetrates clay and enters gravel. Most of the wells run low or dry up in summer. Some persons haul water by hand from near-by springs.

Whitneyville.—The wells in Whitneyville are not more than 20 feet in depth. Some are in gravel and some in clay, and several rest on rock. The wells run dry during the summer and the owners haul water to their houses. At a few houses springs are used.

Jonesboro.—All wells in the town of Jonesboro are dug. One well is situated 50 feet from a granite ledge and is dug 7 feet in boulder clay. This well overflows the surface. A field assay is given in the table (No. 174). One of the interesting features at Jonesboro is the granite water which seeps out of the horizontal joints, as shown in Pl. III, A. This illustration shows that there is plenty of water in granite at this place. A single field assay (No. 174) of water in boulder clay has been made.

Machiasport.—The wells of Machiasport are mostly dug wells, 30 to 40 feet in depth, in sand and gravel. There are some springs in the town. The sardine factory obtains its water from a reservoir supplied by springs.

Jonesport.—Most of the inhabitants of Jonesport use shallow wells and springs. One dug well near the shore is reported to rise and fall with the tide, but the water is fresh. The well of the Seacoast Canning Company is 384 feet deep, in diorite. The water is used for drinking and the yield is reported to be 2½ gallons a minute. It is called hard water. A field assay of this water is appended (No. 159).

On Roque Island the water is said to occur at the contact between the volcanic rocks and the underlying sedimentaries. The well of Mr. George A. Gardner is pumped by a gasoline engine and gives enough water for domestic purposes. It can be pumped dry in twenty minutes, but will fill again in about the same length of time.

Addison.—The village of Addison Point has a public supply from springs which are described under the heading "Public supplies;" otherwise, the inhabitants use only dug wells and springs. One well, 21 feet in depth, penetrated two beds of clay and obtained water in gravel. The Addison Mineral Spring is situated 2 miles southeast of Addisonport.

Columbia Falls.—About half the houses in Columbia Falls are supplied by two springs. The water system is described under the head-

ing "Public supplies." The rest of the inhabitants use dug and driven wells. At Logie's canning factory there is a driven well 72 feet in depth, in which the formation consists entirely of sand. Three gallons a minute are obtained near the bottom of the well. Several other deep driven wells are reported in the town. These generally go through the clay into underlying gravel.

Harrington.—The village of Harrington is supplied by two spring systems, one of which is situated one-half mile northeast of the village and the other 2 miles west of the village, in the town of Columbia. These systems are fully described under the appropriate heading (pp. 225-226). A large part of the town consists of clay. The wells are mostly dug, but some are driven. Many of them go through 25 to 30 feet of clay and enter gravel.

Millbridge.—Millbridge has a public supply from springs situated in the hills a mile west of the town. These springs are fully described on pages 226-227. There are a few wells in the village, but these are mostly abandoned, as they enter a clay bed 35 to 40 feet in depth, in which poor water is found. One well was dug 40 feet and entered a layer of "flats mud" and is now brackish. People who do not use the aqueduct water get their supply from cisterns. There are no drilled wells in the town. The field assay of a shallow bored well in gravel is given in the table (No. 193).

Cherryfield.—The village of Cherryfield obtains water from springs by several small aqueduct systems. These are described more fully under "Public supplies." Some springs supply only two or three families. A few persons have cisterns. There are a number of wells 10 to 40 feet deep in gravel. The water of the wells and springs is good and is never exhausted.

Columbia.—The town of Columbia has few inhabitants and nearly everybody uses water from dug wells and cisterns. In the northern part of the town is a flat plain known as Pineo Ridge, or Blueberry Barrens, standing at an elevation of 250 feet above the sea and having a steep northern slope and deep ravines on its southern slope. These ravines contain many springs of excellent water. The public supply of the town of Harrington comes from springs situated in a swampy depression on a sandy slope in the southwest corner of Columbia.

SPRINGS.

General statement.—Springs are very abundant in Washington County. They are used by a large proportion of the inhabitants of the country districts for drinking purposes, and are also used by many communities for public supplies. The towns of Lubec, Harrington, Millbridge, Addison Point, Calais, Columbia Falls, and Cherryfield all have excellent water supplies from springs. There is at least one commercial mineral spring in the county.

Addison Mineral Spring.—Addison Mineral Spring, owned by the Addison Mineral Spring Company, is situated in the town of Addison, about 4 miles from Columbia station on the Washington County Railway. The spring has been known for a great many years. It was bought by White & Nash about twenty-five years ago, and the water was shipped for a time in barrels. Steps are now being taken to shut out the surface water and otherwise improve the spring. A concrete reservoir 12 feet in diameter and 6 feet in depth has been constructed, in the center of which is the spring. The reservoir generally contains about $3\frac{1}{2}$ feet of water. The owners report the flow to be about a barrel a minute. It bubbles up through coarse gravel overlain by about 4 feet of clay. The run-off contains a considerable deposit of iron.

The composition of the water is given in the table (Nos. 275 and 276). It will be seen that the total solids are 139 parts per million, which is high for a Maine spring water. The water is also said to contain gases, "principally nitrogen, oxygen, and carbon dioxide, with a little hydrogen sulphide." A sanitary analysis in 1906 showed it to be suitable for drinking.

PUBLIC SUPPLIES.

General statement.—Notwithstanding the fact that the villages in Washington County are mostly small, several of them have wisely established public water supplies from the best sources. Machias has a supply from Machias River. Eastport obtains water from Boydens Pond. Calais formerly used St. Croix River water, but this was poor and recently a supply has been installed from St. Stevens, New Brunswick, which seems to be excellent. With these exceptions all the towns having public supplies obtain their water from pure springs issuing from sand and gravel deposits. The communities having such supplies are Lubec, Harrington, Millbridge, Addison Point, Columbia Falls, and Cherryfield.

Lubec.—The village of Lubec owns a system of waterworks piped from a spring situated in drift deposits about 2 miles west of the village. The spring issues from the side of a clay plain, but there is probably gravel and sand underneath. The surface behind the spring is composed of boulder clay and is covered by large boulders. The rock is said to lie 6 feet below the surface. There are no houses within a distance of more than 1,000 yards back on the hill, and there is no chance of the spring becoming contaminated by surface drainage.

Originally this spring was in private ownership, but five years ago it was bought by the town at a cost of \$800, which included a little land about it. This whole hillside appears to be honeycombed with springs, and the water bubbling up out of the sand is very pure and clear and of excellent quality. A small shed has been built over the

spring. The flow is reported to be 100 gallons a minute, and an old resident says it has not diminished in volume during his lifetime. An analysis of the water showed 102 parts per million of total solids, the various constituents of which are reported in No. 282 of the appended table. From the spring the water flows by gravity to a 500,000-gallon reservoir dug in stony boulder clay a few hundred feet distant. From here it is pumped to the village under a pressure of 25 to 45 pounds.

Harrington.—The village of Harrington is supplied by two private companies taking water from springs. The larger one of the two companies is the Quantabacook Water Company, which draws by gravity from a spring situated about 2 miles northwest of the village. This system is owned by several prominent citizens of the town and supplies about 60 families. The waterworks date back to the year 1861, thus being one of the oldest water systems in Maine. In that year wooden pipes were run to town, and some of the original pipes are still in use. In clay their condition deteriorates very little. In gravel, however, it has been necessary to change to iron. The wooden pipes consist of two half logs, put together side by side, with a 2-inch hole bored in the center.

In exact geologic occurrence the water bubbles up out of the sand in a swamp situated near the base of a long, gentle slope of sand and gravel probably underlain by clay. A stick 15 feet long was thrust down into the spring and did not reach the bottom. There are no houses in the vicinity, and the water may be said to be perfectly safe as regards sanitary quality. It is clear and has a fine taste and a measured temperature of only 44°. The flow does not vary with the season. The spring is covered with a small spring house. A fair-sized brook is formed and much more water runs away than can be used. At present about 300 persons are supposed to use the water, and it is said that four times as many people could be supplied. The rates are \$8 for a family, without restrictions. The spring is situated 60 feet above the village and therefore gives a good pressure. The head is said to have diminished somewhat owing to the rotting of the wooden pipes. A field assay is given in analysis No. 278.

The eastern half of the village of Harrington is supplied from a spring situated in sand and gravel deposits about one-half mile northeast of town and not far from the railroad. It is owned by various members of the Nash family. The surroundings are thickly wooded and the water bubbles up similarly to that of the spring owned by the Quantabacook Company. It is supposed to issue from sand near the top of the underlying clay. Although the soil is so thick that the spring can not be seen, the water constantly over-

flows and runs off in the form of a small brook. The water is excellent, is very clear, and has a temperature of 42°. A small spring house is built over the spring.

This company has about 40 takers on its lines. It has no charter, but is a rather old company and still uses wooden pipes. The supply is not as large as that of the Quantabacook Water Company, but there is plenty for all who use it, and the spring is so situated, in the woods and far from any houses, that there is absolutely no danger of its becoming contaminated. The water of this company is similar in quality to that of the Quantabacook Company, being very low in mineral and organic matter. It is said that since these water systems have been installed no case of typhoid fever or diphtheria has originated within the limits of the village.

Millbridge.—The village of Millbridge is supplied by the Millbridge Water Company, which takes water from a spring and a bored well situated in the woods about a mile west of the village. The company was chartered in 1895 and the system was started in 1896. The Millbridge Water Company bought out the old wooden aqueduct company which had been in existence for ten or twelve years and had run a small plant accommodating from 30 to 40 houses.

The spring and the well are situated on the eastern side of a gentle boulder-clay slope which is believed to be underlain by gravel. There are no houses within a distance of three-quarters of a mile, and the water can be said to be absolutely safe from contaminating influences. The water from the spring is piped to town. The well, however, situated near by, is fitted with a windmill and a kerosene engine, which are used in case of drought. The well was dug in 1898, at a time when the spring was rather low. When the wind blows in summer the well water enters the mains and is mixed with spring water. In winter the well is never used. The well passes through 16 feet of till and enters gravel. It is reported that when it penetrated the clay into underlying gravel the water gushed up 12 feet into the air. When not used it now overflows in a small stream. It is curbed with ordinary glazed sewer pipe. The water of this well can be lowered within 4 feet of the bottom by pumping, but no lower.

There seems to be plenty of water at this place, but if it ever is exhausted it will be a very simple matter to dig out other holes such as the well above mentioned. According to surveys made by the company the spring is situated 69 feet above the drawbridge across Narraguagus River at Millbridge. The well is 38 feet below the level of the spring and is only 17 feet in depth. The pump at the well carries the water to a reservoir 50 by 30 feet in size situated near the spring. The pressure is 48 pounds. The owners report that there is no detectable difference in quality between the water taken from

the spring and that taken from the well. Both are fine, clear water with little or no taste. The results of field assays are appended (Nos. 193 and 283). The water mains of the Millbridge Water Company are 6 inches in diameter. The wooden pipes used for years were abandoned and now iron pipe is used.

About 120 water takers are said to be on the lines, including the mills and sardine factories. Probably about 600 people use the water. Nine-tenths of the houses on the south side of the river use it, but none on the north side. The rates are \$10 to a family for a single service, with no restrictions as to the use of the water.

Cherryfield.—Cherryfield is supplied in part by water from the West Side Aqueduct and the East Side Aqueduct companies, the water being taken from two springs situated a short distance from the village. The water issues from gravel about 100 feet above the village. The people who do not use these supplies generally have private aqueducts running to springs in the hillsides. A few, however, use dug wells 10 to 40 feet in depth. All this water is found in gravel below clay. The principal system was installed in 1875. The aqueduct companies use wooden logs for piping. These are said to have rotted out in gravel, but answer the purpose very well in clay. The springs are said to yield plenty of water during the winter, but sometimes they are low during the summer.

Addison Point.—The village of Addison Point is supplied by the Addison Point Aqueduct Company, which has a spring in sand 7 miles from the village and distributes the water by direct pressure through logs. The head is about 60 feet.

PREDICTIONS AND RECOMMENDATIONS.

On account of the sparse population of Washington County few recommendations are necessary. All the public water supplies seem to be of excellent quality, and their use is recommended above that of ordinary well water. In few places does it seem necessary or advisable to spend money in drilling deep below the surface. In communities where well water is scarce and people desire to save water bills drilling may perhaps be done to advantage, as it has been done by several of the canning companies; and when the islands along the coast come to be used more extensively as summer resorts it is probable that deep wells will be needed in order to obtain sufficient supply. Deep-well water can be obtained nearly everywhere. In some of the volcanic areas, however, as at Lubec and Eastport, the quality and amount will be rather uncertain. The poorest water supply is that of Eastport, and the sanitary conditions in this town might be much improved.

YORK COUNTY.

GENERAL DESCRIPTION.

York County is the extreme southwestern county of Maine, bordering on the ocean and on the State of New Hampshire. Its greatest length is 50 miles from north to south and its breadth is 30 miles. The total area is 957 square miles, and the population according to the census of 1900 was 64,885. The largest city is Biddeford, containing 17,165 inhabitants; Saco had 6,122 and Sanford 6,078. The principal rivers are the Piscataqua, separating Maine from New Hampshire, and Saco River, which lies in the eastern part of the county.

The principal transportation lines are the Eastern, Western, and Portland and Rochester divisions of the Boston and Maine Railroad, which cross the county from northeast to southwest, and the York Harbor and Beach Railroad, which connects Portsmouth, N. H., with York Beach. In topography the county is very diversified, ranging in altitude from sea level to about 1,300 feet. The coast is in many places very rocky, but it also contains a number of beaches which are among the finest in the country and are used extensively for summer resorts. A map of York County showing the distribution of deep wells, important springs, and public supplies forms Pl. XXIV.

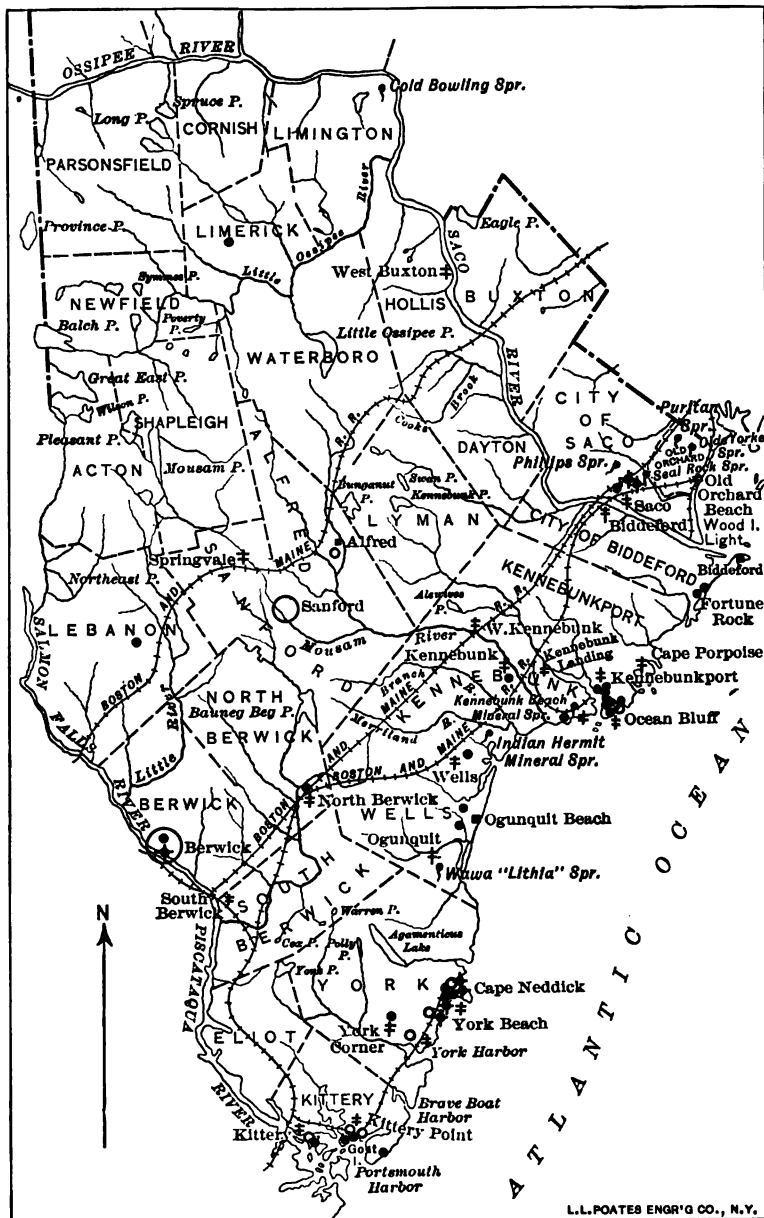
UNDERGROUND WATERS.

RELATION TO ROCKS AND SURFACE DEPOSITS.

Distribution of rock types.—The rocks of York County consist chiefly of slate and granite. They are rather irregularly distributed, but in general the granite can be said to occupy a belt from 5 to 10 miles in width, extending southward from Limington and Hollis to the vicinity of Alfred and Lyman, where it splits into two belts, one of which reaches the coast in the town of Kennebunkport and the other extends as far south as South Berwick and northern York. Outside the granite area the rock is generally slate and schist, which range in character from a rather fissile shaly rock to a hard, dense black slate which is in many places considerably metamorphosed. Much of the rock mapped as slate is in reality schist or quartzite. Both the slate and the granite are cut by a large number of trap dikes.

The prevailing direction of the strike of the slate is from N. 60° to 80° E., and the dip is generally 75° NW. or SE. to vertical. In only a few localities are the dips low. In places the strata are much contorted. The old metamorphic rocks are cut by numerous dikes of basic igneous rock generally known as trap.

All the rocks of York County are very much jointed, but the joint systems are not so definite and regular as in other parts of Maine. An interesting illustration of the way in which water may enter rock and be held in the fissures is given in Pl. V, A. In this locality the



- Successful well over 50 feet in depth
- Unsuccessful well over 50 feet in depth
- ✦ Flowing well
- ✧ Important spring
- ✦ Community having public supply from surface sources
- Community having public supply from wells
- Other important towns

MAP OF YORK COUNTY.

Showing distribution of deep wells, important springs, and communities having public water supplies.

water in the overlying surface deposits will seep slowly downward along the cracks parallel with the stratification and bedding of the slate. Pl. VII, A, shows how it may penetrate along vertical joints.

Surface deposits.—The surface deposits of York County range in thickness from less than 5 feet on some of the hills to more than 100 feet in places along the coast and in some of the larger valleys. Over broad areas on the lowlands there are plains of sand and gravel rising to 100 or 200 feet above the sea and increasing in elevation inland. These are generally underlain unconformably by extensive clay deposits, which in this county reach a maximum elevation of more than 100 feet above tide. Generally abundant water is found in the sand and gravel on top of the clay, and this may be of good quality outside the villages. In some places sand and gravel underlie the clay, and water in this material can be found by driving or drilling wells through the clay formation.

WELLS.

GENERAL DESCRIPTION.

Types of wells used.—Most of the wells in York County, as elsewhere in Maine, are of the old open type, ranging in depth from 10 to 50 feet. These are going out of use and are generally not so satisfactory as drilled wells.

Drilled wells.—The drilled wells more than 50 feet in depth are about 70 in number. So far as known, the deepest well in the county is that of Mr. E. S. Marshall at York Harbor, which was drilled to a depth of 325 feet. There are several wells more than 200 feet deep. The most common depth at which sufficient water is found seems to be about 60 feet from the surface, but some wells did not reach the principal vein until they had gone down more than 200 feet. The head varies greatly. In a few wells the water overflows, but in some others it does not stand within 30 feet of the surface.

Quantity of water.—One well at the United States navy-yard at Kittery reports 15 gallons of water a minute, while a neighboring well reports almost no water. The well belonging to the Boston and Maine Railroad at Kennebunk reports 24 gallons a minute. A well at Cape Neddick reports 30 gallons. With these exceptions the supply is 10 gallons or less. Many persons are using water for domestic supplies when the amount is only about a gallon a minute. The water is generally obtained by hand pump or windmill, but a few wells in the summer resorts are pumped by hot-air engines. In some of the summer resorts many excellent wells have been abandoned in recent years, owing to the installation of satisfactory public supplies. Not more than half a dozen deep wells in the county are known to have been entire failures.

Quality of water.—In quality the water runs from very soft to slightly hard. A few wells along the coast have been ruined by the entrance of salt water. The general quality of slate waters in York County may be judged from analyses Nos. 128 to 131. Two of these are complete analyses and report 169 and 209 parts per million of total solids. A field assay of water in till (No. 167), two of water in sand and gravel (Nos. 194 and 195), and one of water in trap (No. 160) have been made. Several analyses of mineral springs are reported (Nos. 285 to 290), recalculated from the owners' figures.

DETAILED DESCRIPTIONS.

Biddeford.—The city of Biddeford, in conjunction with Saco, has a public supply taken from Saco River. The depth of the few drilled wells in Biddeford is about 100 feet, but only a small amount of water has been obtained. The water was found in granite, but is thought inferior in quality to the usual granite water. Several fair wells have been abandoned on account of installation of city water.

Many wells in this vicinity are dug to rock and obtain water in surface deposits overlying it. A few dug and bored wells in the thickly settled portions of the city are 40 feet or more in depth and obtain water in gravel underlying clay. In one well the water rose to the surface and overflowed. A few wells get water at 10 or 15 feet in sand and gravel.

At Biddeford Pool and Fortune Rock there are a number of drilled wells. At Fortune Rock several summer residents pump water by a windmill from a small pond situated a few feet above tide. This pond water is poor and not safe for drinking.

Saco.—Saco, in conjunction with Biddeford, obtains its public supply from Saco River. A number of bored wells in this city obtain water in clay at a depth of 40 to 50 feet, and the supply seems to be excellent for domestic purposes. Some wells get water at 10 or 15 feet in sand and gravel.

Two or more wells in Saco were drilled in clay to a depth of 55 to 60 feet and obtain flows from gravel below 50 feet or more of clay. Ferrys Beach has good driven wells 10 to 15 feet in depth. Saco owns a well 250 feet deep, which supplies water for drinking fountains.

Old Orchard.—Formerly the public supply of Old Orchard Beach was obtained by gravity from Phillip's spring in Saco. At the present time the water of the Saco River is used.

The wells on Old Orchard Beach are mostly driven and bored in sand to an average depth of 15 feet, the deepest being about 40 feet. The water is usually good, but it is sometimes brackish. Away from the shore drilled wells ought to be successful if sunk into the underlying rock.

Buxton.—In the town of Buxton several shallow drilled wells obtain enough water for domestic use. No very deep drilled wells

have been sunk. The village of West Buxton is now having a public supply installed from Saco River.

Kennebunkport.—The villages of Kennebunkport, Ocean Bluff, and Cape Porpoise are furnished with water by the Mousam Water Company, which obtains its supply from Branch Brook, in Kennebunk. The water is of good quality and for that reason there are not many wells in these villages. A few wells from 10 to 40 feet in depth obtain water in sand on top of clay. A large part of the western part of Kennebunkport consists of a plain of clay sloping seaward and overlain and underlain by sand and gravel. Through this plain the rock reaches the surface in places. Most of the wells are dug. A field assay of water from one well dug in clay at North Kennebunkport is given in the table (No. 167).

In the village of Kennebunkport one drilled well was sunk years ago, but is now abandoned and no information regarding it can be obtained. At Ocean Bluff a number of wells were drilled years ago to depths ranging between 40 and 250 feet. As the public supply has now been installed for several years, all wells have been abandoned and no reliable information about them is at hand.

Kennebunk.—The villages of West Kennebunk, Kennebunk, Kennebunk Landing, and Kennebunk Beach, all situated in the same town, obtain their water supply from the Mousam Water Company, which draws it from Branch Brook. Most houses on the line of the aqueduct outside of the villages also use the town water. There are only a few wells in these villages, and all of these are shallow, being dug or driven to depths of 10 to 30 feet. Plenty of water is obtained from them, but the supply is probably not so safe for drinking as the city water. At Kennebunk Beach a well was once drilled to the depth of 80 feet. The dug and driven wells are mostly sunk in sand and gravel, and some of them rest on clay. At the Mineral Spring House at Kennebunk Beach the Kennebunk Beach Mineral Spring is situated.

Wells.—The villages of Wells, Ogunquit, and Wells Beach obtain their public supply, like the villages in Kennebunk and Kennebunkport, from the Mousam Water Company, the source being Branch Brook. The supply is of good quality. In the village of Wells a few dug and driven wells have been sunk, mostly 12 to 15 feet in depth, in sand and gravel. At Crescent Beach a spring from sand supplies eight cottages. The water is pumped by a windmill to a tank.

Only one or two wells have been drilled here. In the southern part of the town a well was once sunk for Mr. A. P. Littlefield and is reported 100 feet deep in granite, obtaining water at about 50 feet. At Ogunquit two or more wells have been drilled, 60 or 70 feet in depth, and obtain several gallons of water a minute. The water of the well belonging to the Charles C. Hoyt estate at Ogunquit has been analyzed, and the composition is given in the table (No. 131).

York.—At York Harbor a well was drilled for the York Harbor Hotel to a depth of 150 feet, but the supply was small and the well is not much used. At York Beach a well was sunk 60 feet deep in granite and obtained a flow which will rise 2 feet above the surface. Two other wells at this place are reported to overflow the surface from depths of 28 and 60 feet. One of these is said to yield 30 gallons a minute by pumping. Several other wells in town obtain supplies at depths of 40 to 90 feet, and the supply is reported to range between 5 and 10 gallons a minute. The well of Mr. E. S. Marshall, at York Harbor is the deepest in York County. It was drilled 325 feet and was "shot," but let in sea water, and for that reason was abandoned.

Several wells drilled in the town of York have met with failure. Three of these were situated at Cape Neddick, only a few hundred yards from one of the good wells mentioned above. One of these failures was drilled to 87 feet, at which depth salt water was encountered, which rose to about sea level. It is worthy of note that two of the unsuccessful wells were drilled in the trap rock which makes up the greater part of Cape Neddick, and that the third was in schist close to the contact with the trap rock, while the successful wells were in slate and schist. A detailed description of the water resources in the vicinity of York has been given by George Otis Smith.^a

Some water is found at York in and underneath a bed of clay which forms the surface deposit at many places along York River. A small amount seeps out in springs near the bottom of brickyards. One well in a brickyard near York village is dug 18 feet deep in the bottom of a clay pit 8 feet below the surface. The section of this well is as follows: Gray clay, 6 feet; stratified blue clay with thin sand partings, 6 feet; blue clay not stratified, almost quicksand, 6 feet; gravel containing water, 10 feet. A field assay of the water taken from this well is given in the table (No. 195).

Kittery.—Several wells have been drilled on Cutts Island, some at Kittery Point, and several at the navy-yard. At Kittery Point they range from 35 to 60 feet in depth. Mr. Horace Mitchell has five wells from 6 to 60 feet in depth, which together supply the Hotel Champernowne. One of these is drilled 60 feet. The water is pumped from the wells to two cisterns, which together hold 40,000 gallons. In the best season of the summer 200 or more people are supplied by the five wells. The location of two of them is rather poor. It is said that water supplies in slate in this vicinity often give out in dry weather.

The villages of Kittery and Kittery Point are supplied by water from Folly Pond. On Cutts Island there are two drilled wells, one in slate and one in a trap dike. The slate well, owned by Mr. Roland Thaxter, is 75 feet deep; the trap well, belonging to Mr. John Thaxter,

^a Water resources of the Portsmouth-York region, New Hampshire and Maine: Water-Supply Paper U. S. Geol. Survey No. 145, 1905, pp. 122-127.

s 125 feet. The slate well was "shot" twice with 10 pounds of dynamite, but this did not increase the amount of water. The well in trap a few hundred feet distant was a failure, although it was "shot" four times with 15 pounds of nitroglycerin. Near the same point is a well, a few feet deep, blasted in trap in a cellar. A field assay of this water is given in the table (No. 160). This well seems to be safe from surface drainage, as it is bricked up and cemented to the cement floor of the cellar.

Most of the wells in this town obtain only 20 to 50 gallons of water an hour. The well on the grounds of the Hotel Pocahontas, on Gerrish Island, was drilled in 1895 to a depth of 40 feet, the principal source of water being at 39 feet, with other veins at about 30 feet. The well is reported to yield only about a gallon a minute. The water is raised by a windmill and partly supplies the hotel, although there is another source consisting of a natural spring 7 feet above high tide. This spring has been excavated in rock to the depth of 8 feet and when not pumped overflows through crevices of the rock.

At the navy-yard a well was drilled to a depth of 200 feet, obtaining very little water. A second one was sunk to the same depth with a similar result. The first was then deepened to 300 feet, and 15 gallons a minute were obtained.

The most important well in this vicinity is just over the State line, at the Hotel Wentworth, on Newcastle Island, in Portsmouth, N. H. This well is situated near Forts Constitution and Stark. It was drilled some years ago and is supposed to be about 275 feet deep. During midsummer the steam pump has been run night and day at the rate of 30 gallons a minute for two weeks with no appreciable diminution of the supply. The water is of excellent quality.

Eliot.—In the town of Eliot the wells are all dug. Those in the lowlands sunk in clay to moderate depths get a small amount of water. It is of irregular occurrence and seems to occupy more or less well-defined channels in more sandy strata. At one place a pipe was driven 35 feet through clay, and water was not found, showing that it can not be depended on with certainty.

Berwick.—The public supply of Berwick is derived from two wells in gravel. At least two other wells are said to have been drilled, but are now abandoned on account of the installation of city water. A field assay of this water is given in the table (No. 194).

North Berwick.—In North Berwick one well 125 feet deep, sunk in granite, obtains a few gallons of water a minute near the bottom. One or two other drilled wells have been sunk, but no information regarding them has been obtained.

Lebanon.—At Center Lebanon a well was sunk fifteen years ago to a depth of 50 feet. It yields less than 1 gallon a minute, and contains some iron. The water is used, however, for domestic purposes.

Alfred.—Alfred has no public supply, and the water is obtained chiefly from dug and bored wells, mostly 35 to 50 feet in depth. Plenty of water can be obtained a few feet from the surface. Years ago a drilled well was sunk 140 feet, but for some reason was abandoned. There is no reason why drilled wells will not succeed here.

Sanford.—The village of Sanford is supplied with water from a driven well and a dug well situated on the flood plain of Mousam River, midway between that village and Springvale. The supply is satisfactory. It is described under the appropriate heading (pp. 237–238). There are no wells in use in Sanford village. Springvale, in the same town, is situated 2 miles from Sanford, and is supplied by Littlefields Pond, 1 mile north of the village. The water is called poor and is said to have caused typhoid fever, but the pond is situated on the hills where there should be little danger of contamination. Many dug wells are in use in the village. Formerly there were two small water systems here, one obtaining water from springs in sand and gravel deposits at the lower end of the village, the other using river water. In 1904 the spring company was bought out by the other company, and about that time a typhoid epidemic broke out, which was supposed to have been caused by mixing river water with spring water. The springs issue from the base of a gravel terrace rising 20 feet above them, on top of which and several hundred feet distant some houses are situated, but the water is not supposed to be polluted. The largest spring is reported to flow 45 gallons a minute, and the smaller one 30 gallons. The springs are inclosed in small sheds and the water is collected in tanks. They are still used by a few tenants of the owner. Wells in the town of Sanford are all shallow.

SPRINGS.

General statement.—York County is well supplied with spring water. Most of the people in the country districts use wells, but a few have springs. Within the county are a considerable number of springs the water of which is sold. These are as follows:

- Baker Puritan Spring, Old Orchard.
- Cold Bowling Spring, Steep Falls.
- Indian Hermit Mineral Spring, Wells Village.
- Kennebunk Beach Mineral Spring, Kennebunk Beach.
- Olde Yorke Spring, Old Orchard.
- Seal Rock Spring, Saco.
- Wawa Lithia Spring, Ogunquit.
- White Sand Spring, Springvale.

Baker Puritan Spring.—In the town of Old Orchard, about 4 miles west from Pine Point in Cumberland County, is a spring owned by I. C. Baker & Co., of Pine Point. It is situated on a high, dry sandy plain from which the water seeps out of a very fine sand. It is color-

less, odorless, tasteless, and very soft. It is reported to flow about 2 gallons a minute, varying slightly in very dry seasons. It is used as a medicinal and table water.

No chemical analysis has been made of this water. A sanitary analysis made in 1895 by H. D. Evans, chemist, reports 2 parts per million of chlorine, 0.2 part of oxygen consumed, 8.1 hardness, 3.5 of soluble organic matter, and 13.5 of residue of evaporation constituting the total solids; nitrites and nitrates are said to be absent.

Cold Bowling Spring.—In the town of Limington, 1 mile south of Steep Falls post-office, is a spring owned by Messrs. George P. and Frank Anderson, of Boston. The spring is known as the Cold Bowling Spring. The water is reported by the owners to issue from gravel overlain by hardpan. The flow is not large, but it is reported not to vary. The surroundings consist of a level wooded plateau. The water is odorless, is exceedingly pleasant to the taste, and is very clear. The temperature is said to be invariable. The water is sold for table and medicinal purposes at 15 cents a gallon. An analysis, recalculated from that of the owners is given in the table (No. 287).

Indian Hermit Mineral Spring.—About three-quarters of a mile east of Wells village is a spring owned by Mr. C. D. Healey, called the Indian Hermit Mineral Spring. The spring is situated on a hillside and the water is said by the owner to issue from ledge with a volume of 5 gallons a minute. The water is colorless and odorless and has a very pleasant taste. It is sold as a table and medicinal water. The water is said to have been analyzed by Rush & Johnstone, chemists, of Philadelphia, who report it to contain lithia, silica, iron, sodium, magnesium, and other elements.

Kennebunk Beach Mineral Spring.—At the Mineral Spring House at Kennebunk Beach there is a spring owned by Mr. H. K. Smith, the water of which has been sold for table use. The spring is said to have been used by the farmers for years. The hotel was built by Mr. W. F. Paul fifteen years ago, being then called the Grove Hill House. The water is used at the hotel for drinking and cooking, and until city water was installed it was used for other purposes. Considerable water is said to be sold to cottages and hotels in the vicinity and in Kennebunk Beach and Kennebunkport. The water is said to have a very peculiar taste. It was analyzed by S. H. Hitchings, chemist, in 1899 and found to contain 189 parts per million of mineral matter. No quantitative determination of the different constituents was made.

The spring is 12 feet across and 2 or 3 feet deep in the center. It is inclosed in a spring house about 15 feet square. The hotel is situated on a ledge on the hillside, 300 feet distant, and 50 feet above the spring. The spring is well walled up and protected by masonry curbing. The water is pumped by a pitcher pump. It is very clear.

The formation is bowlder clay, but hard blue clay outcrops 40 feet distant, across the road. The spring is only 200 feet from the edge of the salt marsh, which may account for the peculiar taste.

Olde Yorke Spring.—The Olde Yorke Spring, owned by the Olde Yorke Springs Company, is situated at Old Orchard. The water is colorless, odorless, tasteless, and excellent for drinking. As shown by the analysis reported in the circular issued by the owners and recomputed as No. 289 in the table, the water contains 94 parts per million of total solids. It is sold at 20 cents a 1-gallon can.

Seal Rock Spring.—In the town of Saco, about $1\frac{1}{2}$ miles east of the post-office, is the Seal Rock Spring, owned by Mr. M. A. Leavitt. The water is said to boil up from a surface deposit in a valley with a volume of $1\frac{1}{2}$ gallons a minute, which is not supposed to vary with the season. The spring is situated in an open field. The water has no color, odor, or taste, and carries no sediment. No analysis has been made. The water is used for drinking, cooking, and medicinal purposes, and is sold for 5 cents a gallon.

Wawa Lithia Spring.—The Wawa Lithia Spring, owned by Mr. C. W. Dunyon, of Roxbury, Mass., is located 1 mile from Ogunquit, in the town of Wells. The spring is situated in a valley halfway down a hillside, and is said by the owner to issue from a broken granite ledge. It is protected by a small spring house which is kept locked and surrounded by a wire fence. The surroundings are wooded. The water has no color or odor and is very clear. The temperature is low and is said to be variable. The flow is reported to be 1 to 2 gallons a minute with little variation. The water is used for domestic purposes and is sold as a medicinal and table water. The price of a 5-gallon carboy is \$1.50. The analysis in the table (No. 288), is recalculated from that given by the company.

White Sand Spring.—The White Sand Spring is situated on a farm near Springvale and the water is sold in Sanford and Springvale. It is owned by Mr. George G. Plummer. The water is reported to issue at the rate of 5 gallons a minute from granite overlain by gravel, on a rather flat slope. It is colorless, odorless, and tasteless, and its temperature varies with the season. It is used for drinking and cooking and is sold in Sanford and Springvale as a medicinal and table water. The total solids reported in an analysis published by the owner are 42 parts per million, and the hardness is 19.5. A sanitary analysis showed practically no nitrates and very little ammonia, which indicates that the water is probably safe for drinking.

PUBLIC SUPPLIES.

General statement.—A number of communities in York County have public supplies, but only two of them are from underground sources. Probably the best water system in the county is owned

by the Mousam Water Company. The supply is taken from Branch Brook, in the town of Kennebunk, and is used by the villages of West Kennebunk, Kennebunk Landing, Kennebunkport, Kennebunk Beach, Cape Porpoise, Ocean Bluff, Wells, and Ogunquit. Kittery and Kittery Point are supplied by Folly Pond. North Berwick and South Berwick use small brooks. York, York Harbor, and York Beach are supplied by the York Shore Water Company from Chase Lake. Biddeford and Saco obtain their water from Saco River. Formerly Old Orchard was supplied from Phillip's spring in Saco, but at present Saco River water is used. Berwick has a well supply. Springvale uses water from Littlefields pond, although formerly the village was supplied by springs. Sanford has a dug well and driven wells near Mousam River between Sanford and Springvale.

Sanford.—The Sanford waterworks consist of 16 driven wells and a large dug well situated on the flood plain beside Mousam River between Sanford and Springvale. The water is pumped into a reservoir and the pressure is derived in part from that and in part from the pumps at the pumping station near by. The water mains consist of galvanized-iron, wrought-iron, and cast-iron pipes, from 12 inches down to 1½ inches in diameter. It has been thought that the galvanized iron seriously affects the condition of the water, and the pipes sometimes rust through. For that reason the galvanized-iron mains are being replaced by others of cast iron. The capacity of the reservoir is 500,000 gallons and it gives a pressure of 90 pounds.

Until a year ago only the dug well was used, but this water was insufficient and for that reason driven wells were installed. These range in depth from 20 to 30 feet. The water is found in a bed of gravel, which slopes in the same direction as the river, and which is overlain by fine sand and silt; 500 gallons a minute can be pumped for eighteen hours at a stretch. The sand furnishes an excellent natural filter bed, and the supply seems to be perfectly satisfactory.

Berwick.—For five years Berwick has had a supply from driven wells situated on the north edge of the village. The waterworks are owned by the Berwick Water Company. The water is distributed from a reservoir having a capacity of 750,000 gallons and giving a fire pressure of 105 pounds and a regular domestic pressure of 68 pounds. The water is soft and is satisfactory. The mains are about 7 miles in length and there are 30 fire hydrants and 200 taps. About one-tenth of the inhabitants use the public supply. The consumption is 40,000 gallons daily. There is plenty of water and it is reported to be excellent, but persons beyond reach of the mains still use dug wells. A field assay is given in the table (No. 194).

West Newfield.—The people of West Newfield are supplied by a spring, which flows with a volume of 2 gallons a minute. The water is excellent. There are about 1,000 feet of mains and 26 taps.

RECORDS OF DEEP WELLS IN SOUTHERN MAINE.

By W. S. BAYLEY.

The table on the following pages contains the records of 526 wells more than 50 feet in depth obtained to the date of completing the foregoing report. This list was started by correspondence during the years 1903 to 1905, and was completed and revised by field and office work in 1906 and 1907. An effort has been made to include in it all wells, both successful and unsuccessful, more than 50 feet in depth, which have been sunk in southern Maine. In order to make a systematic canvass of the State, blanks were first mailed to the postmasters, asking for the names of well owners and drillers. The majority of postmasters replied to these inquiries, and to the names obtained in that way another blank was sent, requesting full information regarding the locality, owner, year completed, diameter, type, depth of well, depth to rock, depth to principal and secondary water supplies, head of water, quality of water, yield, use, and method of obtaining water from all wells. Replies were received from about half the persons to whom the inquiries were sent. Where the first request met with no reply, a second was sent.

It is probable that a considerable number of wells have been omitted from the list for the reasons, first, that many well owners did not reply to either the first or the second request for information, and, second, that it has been impracticable on account of expense to visit all the wells in the field. Doubtless there are some dug wells more than 50 feet deep which are not included, as all open wells have been dug many years and it is difficult to obtain reliable information concerning them. Some drilled wells are omitted for similar reasons.

It is believed that most of the information given in the table is correct. In preparing such a table, however, inaccuracies are bound to creep in, and it is probable that there have been some mistakes in filling out the blank forms. The list is especially likely to be somewhat in error with respect to the depths at which water was obtained. Few of the local drillers keep accurate records, and in consequence the only data obtainable regarding depth to water are for the most part such as can be recalled by the well owners. The nature of the rock furnishing the supply is seldom reported in corre-

spondence, and many of the reports made are not reliable, for the reason that persons not educated along these lines are unfamiliar with the correct names of rock formations in which water is found. The data in the column headed "Material" are furnished mainly by F. G. Clapp, G. C. Matson, and B. L. Johnson, who investigated the conditions regarding occurrence of water in southern Maine and who have visited most of the wells listed in the table. In the column headed "Quality of water" the terms "hard" and "soft" will be seen to be of frequent occurrence. In only a few parts of southern Maine are there any really "hard" waters, and for that reason the word must be taken only in a relative sense, as comparing the water with some softer water which is familiar to the person making the report.

The compiler wishes to express his thanks and those of the United States Geological Survey to all persons who have assisted in supplying information. They have done a public service to the community.

Records of deep wells in southern Maine.

[Abbreviations: n. r., no rock; +0, just overflows; -0, reaches surface, but does not overflow.]

No.	Locality.	Owner.	Year completed.	Diameter (inches).	Type.	Depth of wall (feet).	Depth to rock (feet).
<i>Androscoggin County.</i>							
1	Auburn	John Pickett			Drilled		0
2	do.	Turner Center Creamery	1904	8	do.	654	90
3	East Auburn	Frank Merrill	1906		Driven	60	n. r.
4	Lewiston	Bates Mill Co.		24	do.	65	n. r.
5	do.	W. R. Bartlett	1899	6	Drilled	103	60
6	do.	F. P. Stetson	1891	6	do.	60	
7	Lisbon Falls	Hugh Douglas			Drilled		4
8	do.	R. A. Small	1889	6	do.	50	10
9	do.	Worumbo Woolen Mills			do.	187	
10	do.	do.	1904		do.	215	0
11	Livermore Falls	W. A. Thompson			do.	65	
12	Mechanic Falls	Portland and Rumford Falls Ry.	1892	6	do.	120	15
13	Poland	W. F. Trask and C. F. Gould	1895	6	do.	140	
<i>Cumberland County.</i>							
14	Baldwin	Frank Milliken	1884	24	Drilled	95	2
15	Bridgton	A. H. Abbott	1891	6	do.	200	35
16	do.	Bridgton Aqueduct Co.		6	do.	290	
16a	do.	The Bridgton		6	do.	70	
17	do.	Rufus Gibbs's heirs		6	do.	113	40
18	do.	J. K. Martin	1890	6	do.	125	20
19	do.	Granville Morrison	1903	6	do.	72	10
20	do.	W. Morrison	1896	6	do.	52	12
21	do.	O. G. Plummer	1890	54	do.	52	10
22	do.	G. Whitehouse	1905	6	do.	70	30
23	Brunswick	Brunswick and Topsham water district.	1904	24	Driven	25-35	n. r.
24	Cape Elizabeth	Geo. G. Brooks		6	Drilled	75	0
25	do.	J. B. Coyle estate		6	do.	80	
26	do.	Geo. T. Cruft	1899	6, 5	do.	127	3
27	do.	James Cunningham			do.	50	4
28	do.	Mrs. E. Dennison	1906	6	do.	60	0
29	do.	Goodrich		6	do.	55	
30	do.	Amos Miller	1894	6	do.	115	2
31	do.	Geo. F. Morse		6	do.	60	0
32	do.	N. W. Morse	1895	6	do.	75	0
33	do.	Shore Acres Land Co.		6	do.	151	3
34	do.	U. S. Government (light-house)	1902	6	do.	149	1
35	Clapboard Island, Falmouth.	S. F. Houston	1899	6	do.	210	6
36	Cow Island	U. S. Government	1905	6	do.	380	
37	Cushing Island	Francis Cushing			do.	275	40
38	do.	S. W. Thaxter et al.	1889	6	do.	70	10
39	do.	do.		8, 6	do.	80	2
40	do.	U. S. Government (Fort Levitt)	1902		do.	550	11
41	do.	do.	1905	8	do.	326	
42	do.	do.	1906	8	do.	277	18
43	do.	do.	1907	8	do.	482	15
44	East Otisfield	Lester Jilson	1888		do.	68	62
45	Falmouth	J. M. Brown	1897	6	do.	205	
46	do.	E. H. Inghalls	1894	8	do.	149	12
47	do.	George Woodward	1900	8	do.	200	
48	Freeport	Clark grist mill	1886	6	do.	1407	30
49	do.	Freeport Granite Co.	1886	6	do.	1607	40
50	do.	Mrs. C. H. Mallett	1888	6	do.	1807	
51	do.	O. W. Shaw & Co.	1886	6	do.	1407	40
52	Gorham	J. H. Carroll	1884	8	do.	92	76
53	do.	Dar. Cressey	1897	8	do.	66	5
54	do.	A. B. Deering	1906	6	do.	80	5
55	do.	Gorham Normal School	1892	6	do.	96	0
56	do.	Melville Johnson	1902	6	do.	90	68
57	do.	Clarence McMakin			do.	80	few
58	do.	H. L. Martin	1900	6	do.	60	17
59	do.	J. H. Rines	1900	6	do.	307	0
60	do.	Fred Smith	1901	8	do.	105	19
61	do.	Wm. E. Strout	1895	8, 6	do.	65	6

Records of deep wells in southern Maine.

[Abbreviations: n. r., no rock; +0, just overflows; -0, reaches surface, but does not overflow.]

Depth to principal water supply (feet).	Depth to other supplies (feet).	Material in which water occurs.	Average height to which water rises (+ above, - below, well mouth).	Quality.	Yield (gallons per minute).	How obtained, where used.	Use, or if not used, the reason why.	No.
63	60	Gneiss			0	Abandoned		1
		do				Not used	No water	2
		Gravel	+ 0	Fair			Drinking	3
		do		Iron and magnesia		Steam pump	Bleaching	4
50		Gneiss	- 20	Good	3	Not used	Too little water	5
47		Granite	- 15	Hard, iron		Pump	Domestic	6
63		do	few	Hard	2	Hand pump	Domestic	7
		do		Sulphur				8
		Gneiss			35			9
		Granite						10
135		do	- 10	Soft		Not used	Too little water	11
		do	+ 0	Hard	18	do		12
								13
198		Granite	- 17	Soft		Windmill	Domestic	14
		do	- 12	do	90	do	Domestic and irrigation	15
		do		Good		Never used	Very little water	16
		do		do	6	Abandoned	Water works installed	16a
115		do	- 75	Soft	20	Hand pump	Not enough for hotel	17
		do	- 10	do	many	Windmill	Domestic and stock	18
45		do	- 12	do	6	do	Domestic	19
		do	- 30	Hard		Pump	Domestic and stock	20
70		do	- 47	Soft	5	Windmill	do	21
3-10		Sand	+ 1 to 0	Hard		Steam pump	Public supply	22
								23
		Schist		Brackish		Abandoned	City water installed	24
75	60	do	- 27	Hard		Windmill	Domestic and stock	25
		do		Good	many		Domestic	26
		Schist		Hard		Hand pump	do	27
								28
115	90	Schist	- 6	Hard	few	Windmill	Domestic	29
		do	- 5	Hard		Windmill	Domestic	30
		do	- 30	Good	many	do	Domestic and stock	31
140	60	Slate	- 6	Alkaline	32	do	Domestic and stock	32
200	60		- 35	Good		do	Drinking and stock	33
						Hot-air engine	Domestic and stock	34
			+ 0		20			35
		Gneiss	- 50	Fair	10	Steam pump	Public supply	36
		Schist	- 25	Good		Windmill	Domestic	37
		Gneiss				do	do	38
280	60, 45	Schist	- 20	Good	10	Not used	Water gave out	39
		do	- 20	Iron	30	Supply of fort		40
180	464	do	- 18		5	Steam pump	do	41
						do	do	42
204				Hard		Windmill	Domestic and stock	43
				Soft	40	do	Domestic	44
200	50		- 6	Hard		do	do	45
			- 40			Pump	do	46
			- 40			Not used	City water installed	47
160			- 5			do	do	48
			- 50			Not used	City water installed	49
92		Slate	- 75			Windmill	Domestic	50
66	few	do	- 4	Hard		Hand pump	do	51
60	80	do	- 30	Good		Pump	Domestic and stock	52
92			+ 1	Hard		Not used		53
85		Slate	- 40		1½	Windmill	Domestic and stock	54
		Schist		Little hard			Domestic	55
		Slate	- 14	Hard	5	Windmill	Farm	56
	30	do	- 30	do		do	Domestic and stock	57
		do	- 18	Soft		do	Domestic	58
63		Schist	- 9	Hard		Hand pump	Domestic and stock	59
								60
								61

Records of deep wells in southern Maine—Continued.

No.	Locality.	Owner.	Year completed.	Diameter (inches).	Type.	Depth of well (feet).	Depth to rock (feet).
<i>Cumberland County—Continued.</i>							
62	Great Chebeague Island.	Ellis Ames Ballard.	1893	6	Drilled.	301	
63	Great Diamond Island.	Diamond Island Association.	1893	6	do.	120	8
64	do.	do.		6	do.	96	6
65	do.	W. A. Stone.	1900	6	do.	215	6
66	do.	U. S. Government (Fort McKinley).			do.	302	
67	do.	do.	1902	6	do.	97 $\frac{1}{2}$	10
68	do.	do.	1902	6	do.	265 $\frac{1}{2}$	
69	do.	do.	1902	6	do.	95	8
70	do.	do.	1899	6	do.	265	16
71	Harrison.	Dan Caswell.			do.	65	20
72	do.	Ben Harmon.			do.	90	
73	House Island, Portland.	U. S. Government (quarantine).			do.	270	0
74	Little Chebeague Island.	J. H. Hamlin.			do.	197	100±
75	Little Diamond Island.	U. S. Government (light-house).	1902	8	do.	171	6
76	Mere Point.	W. D. Pennell.		6	do.	67	0
77	Naples.	Mrs. A. F. Perly.	1885	8	do.	210	13
78	New Gloucester.	Shaker Society.	1885	6	do.	150	
79	Otisfield.	Lester Jilson.			do.	100+	
80	Peaks Island.	Beacon Hill Water Co.		6	do.	93	0
81	do.	Sue Cole.		6	do.	75	
82	do.	Tom Frothingham, Jr.	1899	6	do.	90	0
83	do.	C. W. T. Goding.	1900	8	do.	135	
84	do.	Hillburn estate.			do.	60	14
85	do.	Peaks Island Water and Light Co.	1898	8	do.	202	0
86	do.	do.	1905	8	do.	203	0
86a	do.	do.	1907	8	do.	201	2
87	do.	Harriet M. Skillings's heirs.			do.	80	
88	do.	J. H. Tolman.	1886	8, 6	do.	97	3
89	Portland.	Jas. P. Baxter.	1885	6	do.	164	0
90	do.	Chas. A. Brown.			do.	90	
91	do.	Burgess-Forbes & Co.	1887	6	Drilled.	288 $\frac{1}{2}$	149 $\frac{1}{2}$
92	do.	E. T. Burrows & Co.	1891	6	do.	106	5
93	do.	Consolidated Electric Light Co. of Maine.	1887	8	do.	204	8
94	do.	D. F. Emory.	1906	6	do.	128	42
95	do.	Foster's dye house.	1886	6	do.	140	0
96	do.	Mary J. Frazer.		6	do.	210	
97	do.	M. R. Griffith.	1897		do.	178	30
98	do.	Maine General Hospital.	1892	6	do.	505	100+
99	do.	do.	1901	10, 8	do.	830	97
100	do.	John T. Palmer.	1897		do.	161	4
101	do.	Y. M. C. A. building.	1898	9	do.	96	0
102	Scarboro.	Walter Briggs.			Dug.	56	
103	do.	Ira C. Foss.		6	Drilled.	290	
104	do.	H. J. Libby estate.	1905	7	do.	201	19
105	do.	S. D. Plummer.		8	do.	127±	1
106	Sebago Lake.	Chas. Dolloff heirs.	1885	6	do.	60	
107	South Freeport.	G. A. Dixon.	1888	6	do.	100	6
108	do.	J. H. Leo.	1901	6	do.	108	0
109	South Windham.	J. L. Robinson.	1902	6	do.	121	41
110	Standish.	Jno. W. Bowers.	1902	6	do.	60	12
111	do.	Mrs. G. W. Granville.	1901	6	do.	60	50
112	do.	Almond Marcan.	1897	6	do.	63	
113	do.	Frank H. Rand.	1900	6	do.	78	8
114	do.	R. W. E. Shaw.	1897	6	do.	98	
115	Westbrook.	Haskell Silk Co.	1904	6	do.	216	6
116	do.	do.	1904	6	do.	200	0
117	do.	Rufus Jordan.	1903	6	do.	216	
<i>Franklin County.</i>							
118	Farmington.	Warren Ladd.	1850		Dug.	58	
119	North Jay.	Leon H. Look.	1903	2	Driven.	70	n. r.

Records of deep wells in southern Maine—Continued.

Depth to principal water supply (feet).	Depth to other supplies (feet).	Material in which water occurs.	Average height to which water rises (+ above, - below, well mouth).	Quality.	Yield (gallons per minute).	How obtained, where used.	Use, or if not used, the reason why.	No.
55		Schist	+ 15	Good	12	Windmill	Domestic	62
		Slate	+ 0	Hard	12	Hot-air engine	Public supply	63
		do	+ 15	do	15	do	do	64
		do	+ 0	Soft	8	Steam pump	Domestic	65
		Schist	- 20	Good	14			66
80		Slate	+ 0	Hard	25			67
100		do	+ 3	do	15	Not used		68
80		do	+ 0	do	30			69
35		do	- 8	Soft	60	Steam pump	Domestic	70
		Granite		Good				71
		do				Abandoned	House burned	72
		Schist			15	Windmill	Domestic	73
		do				Not used	Water gave out	74
160		Slate	- 6	Salty	4	do	Water too salty	75
		Schist				Hand pump	Domestic	76
35			- 24		1	Steam pump	Stock and irrigation	77
			- 35		1	Not used		78
23		Granite			25	Hot-air engine	Public supply	79
		Schist	- 10		few	Hand pump	Domestic	81
90		do	- 10	Hard, little iron	5	do	Domestic and stock	82
		do	+ 0	Little iron	52	Steam pump	Boilers and hotel	83
60		do			many	Hand pump	Domestic	84
		do		Hard	85	Steam pump	Public supply	85
193		do	- 28	do		do	do	86
140	90	do	- 30	do		do	do	86a
		do				Hand pump		87
84		do		Soft	2	Windmill	Domestic	88
164		Slate	- 1	Hard			Business block	89
60		do	- 10	Soft				90
160	288	do	- 160	Soft, alkaline	14	Steam pump	Boilers and drinking	91
106		do	- 15	Hard		do	Fire service and washing	92
136	29	do	- 9	Salty	65	Not used	Water too salty	93
120		do	- 42	Soft	11	Windmill		94
60		do	- 12	do	30	Pump	Dye house	95
		do	+ 0	do	25	Windmill	Supplies many tenements	96
		do	- 78	Hard				97
405	506	do	- 100	Soft	13	Steam pump	Domestic and boilers	98
97		Gravel	- 100	do	3	Not used	Too little water	99
		Slate		Hard				100
38		do		do	26	Abandoned	Sometimes brackish	101
			- 54			Windmill	Domestic	102
275				Salty		Not used	Water salty	103
200	40	Slate	- 14	Hard	8	Windmill	Domestic and stock	104
		do	- 8	do	many	do	do	105
			- 10	Soft		do	do	106
	15		- 4	Medium		Hand pump	Domestic and factory	107
	35	Granite	- 18	Hard	1	Windmill	Domestic	108
		Slate	- 40	Muddy	5	Not used	Poor water	109
59			- 15	Soft		Hand pump	Domestic	110
60		Schist	- 4	do	4	do	do	111
13			- 13	Hard		do	do	112
71	50	Schist	- 4	Soft	9	do	Domestic and stock	113
		do	- 26	Hard	3	do	Farm	114
200	50	Slate and granite	+ 0	Hard, sulphur	34	Air lift	Manufacturing	115
200	50	Slate	- 16	do		do	do	116
216		do	+ 8	Hard	2	Natural flow	Domestic	117
58		Clay				Windlass	Domestic	118
						Not used	Too little water	119

Records of deep wells in southern Maine—Continued.

No.	Locality.	Owner.	Year completed.	Diameter (inches).	Type.	Depth of well (feet).	Depth to rock (feet).
<i>Hancock County.</i>							
120	Bar Harbor.....	Edw. Morrell.....	1902	6	Drilled.....	87½	2
121	Black Island.....	Brown & McAllister.....	1883	6	do.....	74	4
122	Bluehill.....	A. M. Thomas.....	1905	.....	do.....	140	20
123	do.....	A. S. Thomas.....	.....	.....	do.....	208	.....
124	Bluehill Falls.....	Mrs. Ethelbert Nevins.....	1905	.....	do.....	90	.....
125	Brooklin.....	Brooklin Packing Co.....	.....	6	do.....	112	2
126	do.....	Wm. W. Dodge.....	.....	6	do.....	104	.....
127	do.....	G. S. Stevens.....	1888	5	do.....	87	4
128	do.....	Noah V. Tibbetts.....	1904	4	do.....	55	.....
129	do.....	Mrs. Wilson.....	.....	.....	do.....	80	few
130	Bucksport.....	Melville Chapman.....	1891	6	do.....	308	0
131	do.....	Eastern Maine Conference Seminary.....	1902	6	do.....	368	43
132	Castine.....	Acadian Hotel Co.....	1906	6	do.....	58	14
133	do.....	Castine Water Co.....	1893	7	do.....	70	14
134	do.....	do.....	1893	7	do.....	80	14
135	do.....	do.....	1894	8	do.....	110	14
136	do.....	do.....	1896	7	do.....	675	12
137	do.....	do.....	1899	8	do.....	50	7
138	do.....	Geo. W. Perkins.....	1893	7	do.....	303	.....
139	Crotch Island, Stonington.....	Ryan-Parker Construction Co.....	1906	.....	do.....	87½	n. r.
140	East Orland.....	Tom Mason.....	.....	6	Driven.....	207	9
141	Great Cranberry Island.....	Moorefield Storey.....	1904	6	Drilled.....	250	.....
142	do.....	do.....	1907	.....	do.....	110	.....
143	Greening Island.....	Colton.....	1903	.....	do.....	90½	2
144	do.....	J. G. Thorp.....	1896	6	do.....	98	4
145	Hancock.....	Hancock Water, Gas and Power Co.....	1880	100	Old mine shaft.....	65	5
146	do.....	D. H. Saunders.....	1888	6	Drilled.....	50	12±
147	do.....	E. L. Stratton.....	1904	6	do.....	65	4
148	do.....	Jeremiah Stratton.....	1905	6	do.....	30	n. r.
149	do.....	Town of Hancock.....	1902	2	Bored.....	78	0
150	Isle au Haut.....	Mrs. R. A. Sturtevant.....	1895	6	Drilled.....	50	0
151	Little Cranberry Island.....	Miss Frothingham.....	1903	6	do.....	60	5
152	Mount Desert Ferry.....	F. L. Colby.....	1888	6	do.....	65	.....
153	do.....	I. G. Crabtree.....	1888	6	do.....	37	3
154	North Sullivan.....	C. H. Abbot.....	1903	6	do.....	51	0
155	do.....	Crabtree & Havey.....	1902	6	do.....	189	0
156	Northeast Harbor.....	L. E. Kimball.....	1900	6	do.....	90	7
156a	do.....	J. G. Thorp.....	1896	6	do.....	43	2
157	Orland.....	A. H. Dresser.....	1899	6	do.....	42	2
158	do.....	A. W. Emerson.....	1890	6	do.....	77	12
159	do.....	Mrs. A. W. Hutchins.....	.....	6	do.....	65	4
160	do.....	A. J. Jordan.....	1887	6	do.....	37	4
161	Otter Creek.....	Mrs. Birge.....	1899	6	do.....	450-60	n. r.
162	Sorrento.....	Frank Jones estate.....	1896	2	Driven.....	92	4
163	do.....	do.....	1891	6	Drilled.....	114	.....
164	do.....	Isaac Lawrence.....	.....	6	do.....	61	0
165	do.....	William Lawrence.....	1892	7	do.....	136	.....
166	Southwest Harbor.....	Southwest Harbor Water Co.....	1891	6	do.....	125	.....
167	do.....	do.....	1895	6	do.....	297	6
168	do.....	do.....	1899	5½	do.....	144	2
169	Stonington.....	Geyer & Torey.....	1900	5½	do.....	67½	2½
170	do.....	Samuel Goss.....	1893	5½	do.....	183	0
171	do.....	Pine Lake Water Co.....	1896	6	do.....	94	0
172	do.....	J. C. Rogers & Co.....	1906	6	do.....	279	0
173	do.....	do.....	1908	6	do.....	98	0
174	Sullivan.....	Dwight Braman.....	1889	10	do.....	120	0
175	do.....	do.....	.....	.....	Blasted and drilled.....	108	30
176	do.....	S. V. Bennis.....	.....	6,5	Drilled.....	199	6
177	Suttons Island.....	Wm. Burnham.....	1902	6	do.....	.....	.....

a 14 wells.

Records of deep wells in southern Maine—Continued.

Depth to principal water supply (feet).	Depth to other supplies (feet).	Material in which water occurs.	Average height to which water rises (+ above, — below, well mouth).	Quality.	Yield (gallons per minute).	How obtained, where used.	Use, or if not used, the reason why.	No.
87 70	50	Granite	— 3	Good.		Hand pump.	Stock.	120
		do.	— 3	Iron.	15	do.	Domestic and quarry supply.	121
		Gneiss.	— 0	Soft, muddy.	many	Hot-air engine.	Stock.	122
		do.		Iron.	7 1/2	Hand pump.	Domestic.	123
		do.			many	Hot-air pump.	do.	124
		Granite	— 26	Good.	2 1/2	Windmill.	Sardine factory.	125
103 87	20, 40	do.	— 20	Good.	2 1/2	Pump.	Domestic.	126
	20, 60	do.	— 0	Soft.	many	Steam pump.	Domestic and boiler.	127
		Granite.	— 20	Good.	few	Hand pump.	Domestic.	128
70 100	20	Quartzite.	— 20	Iron.	many	do.	Domestic.	129
	300±	Slate.	— 8	Hard, iron.	many	Gasoline engine.	Washing and boilers.	130
278		Volcanic tuff.	— 15	Hard.	10	Hot-air engine.	Hotel.	132
		do.	— 25	Soft.		Not used.	Drill stuck.	133
62		do.	— 25	do.	27	Windmill and steam pump.	Public supply.	134
62		do.	— 25	do.		do.	do.	135
62		do.	— 25	do.		do.	do.	136
620 48	40	do.	— 27	do.	13	Windmill.	Little used.	137
		do.	— 8	do.		do.	Dairy.	138
		Granite.		Salty.		Not used.	Water salty.	139
		Sand.	— 40	Good.	8	Windmill.	Domestic and stock.	140
		Felsite.			1	Not used.	Too little water.	141
		do.			few			142
90 86	45	Granite.	— 9	Salty.		Not used.	Water salty.	143
		do.	— 3	Soft.		Windmill.	Domestic.	144
		do.	— 3	Little hard.		Windmill and gasoline engine.	Public supply.	145
62 30	50	Schist.	— 12	Soft.	few	Hand pump.	Stock.	146
50 30		do.	— 20	do.	many	do.	Domestic.	147
30 72	30	Gravel.	+ 5	Soft.	10	Natural flow.	do.	148
		do.	— 4	do.	10	Windmill and gasoline engine.	Drinking fountain.	149
50 60			— 6		5	Hand pump.	Domestic and stock.	150
10 37		Granite.	— 10	Soft.		do.	Domestic.	151
18 180		do.	— 10	Good.	16	Pump.	do.	152
		do.	— 10	Little iron.	many	Hand pump.	do.	153
86 30		do.	— 83	do.	40	do.	do.	154
		do.	— 7	Soft.	10	Not used.	City water installed.	155
23 42		Slate.	— 20	Hard.		Windmill and gasoline engine.	Domestic and irrigation.	156a
67 60	23, 44	do.	— 20	Hard, good.		Hand pump.	House unoccupied.	157
34 50-60		Slate.	— 50	Iron.		do.	Domestic.	158
		Granite.	— 7	Iron, muddy.		do.	do.	159
		Sand.	+ 0	Good.		Not used.	Poor water.	160
		do.		do.		Hand pump.	Domestic.	161
		do.		do.		Abandoned.	Formerly village supply.	162
90 56		Slate.	— 11	Soft.	6	Not used.	Brackish.	163
120 95		Granite.	— 14	Soft.	4	Not used.	Brackish.	164
		do.	— 80	Hard.	50	do.	Brackish.	165
		do.	— 9	Soft.	45	Gasoline engine and windmill.	Public supply.	166
		do.	— 30	Medium.	100	do.	do.	167
144 65	35	do.	— 7	Soft.	1 1/2	Windmill.	Domestic.	168
		do.	— 7	Hard.	3	Windmill and gasoline engine.	Supplies 15 families.	169
180 45	38	do.	— 18	Soft.	28	Not used.	Never connected.	170
210		do.	— 4	Good.	60	Steam pump.	Quarrying.	171
		do.	— 8			do.	do.	172
		do.				Hand pump and windmill.	Drinking.	173
		do.						174
		do.						175
		Slate.				Not used.	Too little water.	176
199 174		Trap.	— 6	Soft.	20	Gasoline engine.	Domestic.	177

Records of deep wells in southern Maine—Continued.

No.	Locality.	Owner.	Year completed.	Diameter (inches).	Type.	Depth of well (feet).	Depth to rock (feet).
<i>Hancock County—Con.</i>							
178	Suttons Island.....	Church & Burnham.....		5½	Drilled.....	90	
179	Trenton.....	Geo. J. Safford.....	1904	6	do.....	54	22
180	Washington Junction.....	H. B. Phillips.....				130±	
181	West Sullivan.....	J. Clapham.....	1889	6	Drilled.....	61	20
182	do.....	V. B. Gordon.....			Old mine shaft.	410	
<i>Kennebec County.</i>							
183	Albion.....	A. S. Besse.....	1876	7		45	
184	Augusta.....	G. P. Sanborn.....	1898	6	Drilled.....	560	0
185	Farmingdale.....	H. M. Hodgdon.....	1899	6	do.....	108	3
186	do.....	Tibbetts & Sawyer.....	1899	6	do.....	80	2
187	do.....	Charles Trask.....	1899	6	do.....	56	39
188	Gardiner.....	Chas. Hopkins.....	1890	6	do.....	34	5
189	Hallowell.....	H. G. Vaughan.....	1890	6	do.....	70	20
190	Litchfield.....	Harlan P. King.....	1891		do.....	77	10
191	Pittston.....	C. C. Libbie.....	1890		do.....	56	10
192	do.....	B. E. Moody.....		5	do.....	100	
193	do.....	do.....		5	do.....	85	
194	do.....	L. E. Moody.....	1890	5½	do.....	135	4
195	Sidney.....	J. J. Frye.....	1886		do.....	230	
196	do.....	G. F. Bowman.....	1902	6	do.....	92	66
197	Vassalboro.....	American Woolen Co.....	1902		do.....	50	
198	Winslow.....	J. L. Dean.....	1904	6	do.....	65	5
199	do.....	Hollingsworth & Whitney Co. a.....	1899	6	do.....	110-125	
200	do.....	do.....	1901	6	do.....	67	5
201	do.....	Ralph Simpson.....	1904	6	do.....	55	5
202	do.....	J. P. Taylor.....	1890	5	do.....	65	9
203	do.....	Chas. Withie.....	1904	6	do.....	55	5±
204	Winthrop.....	C. M. Bailey Sons & Co.....	1906	6	do.....	307½	36
205	do.....	C. H. Gale.....	1895	6	do.....	87	0
206	do.....	do.....			do.....	96	
207	do.....	do.....			do.....	65	
208	do.....	do.....	1899	6	do.....	120	50
209	do.....	H. P. Hood & Son.....	1903	8	do.....	172	18
210	do.....	Frank S. Wood.....	1905	8	do.....	176	2
211	Winthrop Center.....	C. I. Bailey and J. Briggs.....	1890	5½	do.....	200	9
212	do.....	C. M. Bailey.....	1893	5½	do.....	184	12
213	do.....	E. A. Bailey.....	1899	5	do.....	113	4
214	do.....	Mrs. Hannah J. Bailey.....	1898	6	do.....	200	
<i>Knox County.</i>							
215	Appleton.....	F. J. Oakes.....	1900	6	do.....	320	
216	Crescent Beach.....	F. M. Smith.....	1906	6	do.....	75	1
217	High Island.....	W. Gray & Sons.....	1905	6	do.....	230	
218	North Haven.....	H. W. Chaplin.....	1891	6	do.....	200±	0
219	do.....	W. A. Gaston.....			do.....	57	
220	do.....	Lewis Herzog.....	1905	6	do.....	164	
221	do.....	Henry Jackson.....	1904		do.....	150	
222	do.....	F. S. Mead.....	1896		do.....	126	0
223	do.....	Nelson Mullen.....	1893	6	do.....	121	6
224	do.....	Chas. S. Rackeman.....			do.....	165	
225	do.....	F. H. Smith.....	1893	6	do.....	118	3½
226	do.....	C. S. Staples and J. M. Howe.....	1902	6	do.....	300	
227	do.....	do.....	1902	6	do.....	200	0
228	do.....	C. G. Wells.....	1903	5½	do.....	282	2
229	do.....	do.....	1896	6½	do.....	142	2½
230	do.....	do.....	1891	6	do.....	122	3½
231	Rockland.....	Rockland Machine Co.....	1900	6	do.....	97	
232	Rockland Breakwater.....	Ricker Hotel Co. (Hotel Samoset).....	1906	8	do.....	640	14
233	Tenants Harbor.....	J. B. Aldrich.....	1894	5½	do.....	54	
234	do.....	Wm. S. Richardson.....	1894	6	do.....	67	10

a 7 wells along a 90-foot line.

Records of deep wells in southern Maine—Continued.

Depth to principal water supply (feet).	Depth to other supplies (feet).	Material in which water occurs.	Average height to which water rises (+ above, — below, wall mouth).	Quality.	Yield (gallons per minute).	How obtained, where used.	Use, or if not used, the reason why.	No.
85			— 9	Sulphur.	14	Not used.		178
			— 10	Good.	20	Hand pump.	Domestic and stock.	179
40	61		— 8	Mineral.	5	Not used.	Bad taste.	180
						Siphon.	Boilers.	181
								182
25	10		— 35	Hard.	few	Windmill.	Domestic.	183
180		Granite.	— 400	Soft.	few	do.	Irrigation.	184
104		Slate.	— 7	do.	5	Pump.	Domestic and stock.	185
75		do.	— 9	do.	54	Hand pump.	Milk farm.	186
53		do.	— 9	do.	20	do.	Domestic and stock.	187
25		Schist.		Medium.	many	Windmill.	do.	188
70	20	Slate.	— 15	Hard.		Not used.	Poor water.	189
50	30	do.				Pump.	Domestic.	190
53			— 9	Soft.	10	Hand pump.	Domestic and stock.	191
10			— 4			Not used.	Drilled for ore.	192
						do.	do.	193
132	77		— 9	Soft.	8	Hand pump.	Domestic and stock.	194
230		Slate.						195
70		do.	— 30	Soft.	14	Windmill.	Domestic.	196
		Slate.	— 14			do.	do.	197
			— 27	Little hard.	60	Hand pump.	Domestic and irrigation.	198
		do.	— 7			Air lift.	Cooling acid, but now abandoned.	199
63		do.	— 8			Hand pump.	Drinking.	200
		do.						201
		do.		Hard, iron.	15	Hand pump.	Drinking and stock.	202
		do.			few			203
300		Schist.	— 9	Good.	50	Steam pump.	Boilers.	204
25		do.	— 12			Windmill.	Public supply.	205
		do.		Good.		do.	do.	206
		do.		do.		do.	do.	207
		do.	— 20	Hard.	many	Siphon.	do.	208
100		do.	— 7	Good.	25	Steam pump.	Creamery.	209
	100	do.	— 20	do.	4	Electric pump.	Domestic.	210
	195	do.	— 7	do.	20	Windmill.	Domestic and stock.	211
183		do.	— 27	do.	30	Steam pump.	Boilers.	212
112	15	do.	— 3		12	Windmill.	Domestic and stock.	213
		do.	— 50	Good.	15	do.	do.	214
60			— 10	Soft.	15	Not used.		215
		Complex.	— 2	Variable.	6	Windmill and gasoline engine.	Public supply.	216
		do.						217
175			— 25	Little hard.	72	Windmill.	Domestic.	218
				Poor.	34	Abandoned.	Ruined by accident.	219
				Soft.		Gasoline engine.	Domestic.	220
125		Trap.		Hard.	10	Windmill.	do.	221
118	67	do.	— 7	Little iron.	44		Hotel and 5 cottages.	222
		do.		Good.				223
116				Soft.	4	Windmill.	Domestic and stock.	224
					dry	Not used.	No water.	225
64			— 14	Hard.	3	do.	Too little water.	226
68			— 35	Medium.	6	Windmill.	Domestic.	227
140			— 9	Hard.	20	Windmill and hot-air engine.	Cottage and yachts.	228
								229
112			— 9	Salty.	24	Windmill.	do.	230
90			— 20	Soft.	40	Not used.	Too salty.	231
185					10	do.	Too little water for hotel.	232
50		Gneiss.	— 12	Soft.		Windmill.	Domestic.	233
66		do.	— 20	Hard.	2	do.	do.	234

Records of deep wells in southern Maine—Continued.

No.	Locality.	Owner.	Year completed.	Diameter (inches).	Type.	Depth of well (feet).	Depth to rock (feet).
<i>Knox County—Cont'd.</i>							
235	Thomaston	Thomaston Brick Co.			Drilled	386	
236	Vinalhaven	Bodwell Granite Co.	1880	6	do.	125	
237	do.	Wm. B. Clark and others.	1903		do.	220	6
238	do.	H. L. Francis		6	do.	185	12
239	do.	J. M. Howe	1897	5½	do.	120	2½
240	do.	Sanborn, Glidden and Raymond.	1904	4	do.	203	0
241	do.	Alex. Strong.	1897	5½	do.	181	5
242	do.	Vinal Haven Fish Co.	1903	6	do.	225	0
243	do.	G. W. Wheelwright.	1899	6	do.	180	0
244	Warren	Warren Water Co.	1903	6	do.	196	4
245	Washington	A. E. Poland	1905	6	do.	95	5
246	West Rockport.	Oscar Gould.	1885	6	do.	50	3
247	Widows Island.	Maine Insane Hospital.	1906	6	do.	109	6
<i>Lincoln County.</i>							
248	Birch Island. South Bristol.	E. A. Means.	1901	6	Drilled	75	3
249	Bristol.	H. E. Cotton.	1905	6	do.	704	4
250	Bristol Mills.	J. W. P. Goudy.	1905	6	do.	52	12
251	do.	J. C. Hyson	1906	6	do.	624	18
252	Cooper Mills.	Cbas. H. Ashford	1896±	6	do.	65	
252a	Christmas Cove.	D. Y. Comstock.				40	
253	do.	G. K. Denuett.	1902	6	Drilled	50	0
254	do.	T. O. Little & Son.	1902	6	do.	130	16
255	do.	W. E. Little.	1902	6	do.	106	22
256	do.	A. T. Thorpe	1901	6	do.	123½	0
257	do.	A. S. Warner	1903	6	do.	83	0
258	do.	Everett Westcott	1902	6	do.	100	0
259	do.	E. F. Wilder.	1902	6	do.	55	
260	Damariscotta	Mrs. G. C. Chapman.	1902	4	do.	87½	25
261	Damariscotta Mills.	G. W. Waltz.	1905	6	do.	50	12
262	East Boothbay.	Ammonia Works	1891	5	do.	157	10
263	do.	do.	1891	6	do.	154	
264	do.	Fred Curtis	1905	6	do.	94	
265	do.	Hodgdon Bros.	1904	6	do.	120	2
266	do.	Captain Race	1904	6	do.	51	
267	do.	Frank Rice	1904	6	do.	72½	2
268	do.	Frank L. Weston	1904	6	do.	72	0
269	Hodgdons Island, Bristol.	— Stratton.	1905	6	do.	118½	3
270	Inner Heron Island.	Wm. C. Damon.	1904	6	do.	119	0
271	do.	Heron Island Co.	1890	6	do.	624	10
272	Jefferson.	Abram Brann.	1884	6	do.	91	
273	do.	L. R. Hodgkins.	1880	6	do.	119	0
274	Linekin Neck	F. C. Lowden.	1901	6½	do.	250	0
275	do.	John A. Royal.	1904	6	do.	95	0
276	Newcastle.	J. M. Glidden	1892	5	do.	85	12
277	do.	W. T. Glidden.	1892	5½	do.	88½	9
278	do.	S. D. Wyman.	1902	6	do.	76	
279	New Harbor.	E. W. Fossett.	1901	6	do.	33	
280	do.	F. A. Fossett.	1901	6	do.	140	3
281	do.	C. T. Poland.		6	do.	33	
282	North Boothbay.	Paul Conklin.	1904	6	do.	142½	
283	North Edgcomb.	F. R. Curtis.	1905	4	do.	84	0
284	North Whitefield.	John Dowden.	1889	6	do.	105	35
285	do.	A. R. G. Smith	1889	6, 5	do.	114	9
286	Ocean Point.	L. J. Crooker.	1903	6	do.	360	0
287	do.	— Emerson	1904	6	do.	67½	
288	Pemaquid Beach.	C. A. Sproul.	1901	6	do.	42	3
289	Pemaquid Point.	Chamberlain & Elliott.	1900	6	do.	55	0
290	do.	W. A. Elliott.	1901	6	do.	51	0
291	South Bristol.	N. W. Gamage.	1902	6	do.	102	
292	South Newcastle.	Mrs. C. A. McMichael.	1901	6	do.	56	10
293	Squirrel Island.	K. H. Richards		6	do.	200	0
294	Waldoboro.	R. L. Benner.	1902	6	do.	41	2

Records of deep wells in southern Maine—Continued.

Depth to principal water supply (feet).	Depth to other supplies (feet).	Material in which water occurs.	Average height to which water rises (+ above, - below, well mouth).	Quality.	Yield (gallons per minute).	How obtained, where used.	Use, or if not used, the reason why.	No.
		Limestone.		Hard	4			235
50		Granite.	- 3	do.		Gasoline engine.	Granite dressing.	236
		do.		Brackish		Pump.	Washing.	237
180			-14		10	Windmill.	Cottage and yacht.	238
115		Trap.	- 7	Medium.	22	do.	4 cottages.	239
60		Granite.	-27	Hard.	8	Hand pump.	Domestic.	240
175		Trap.	- 7	Soft.	25		do.	241
215	50, 75	Granite.	-30	Alkaline.	20	Gasoline engine.	Canning factory.	242
		Trap.	-15	Hard.	5	Windmill.	Domestic and stock.	243
165			+ 5	Soft.	100	Windmill and gasoline engine.	Public supply.	244
95	40	Complex.	-22		8	Hand pump.		245
27		do.		Soft.		do.	Domestic and stock.	246
70	40, 100		- 5	Hard.	3	Gasoline engine.	Domestic.	247
73	30	Complex.	-12	Soft.	2	Hand pump.	Domestic.	248
		do.	-30		1		do.	249
52	35	do.	-15	Good.	1	Hand pump.	do.	250
50		do.	- 9	Iron.	5	do.	Domestic and stock.	251
		Gneiss.		do.		do.	Drinking.	252
		Complex.						252a
50	35	do.	-40	Hard.	14	Hand pump.	Domestic.	253
128	60	do.	- 6	Soft.	12	Windmill.	Summer hotel.	254
86	50	do.	-20	do.	2	do.	do.	255
94		do.	- 8	Good.		Not used.	Hotel burned.	256
		do.	-52	Hard, good.		Windmill.	Domestic.	257
92	40	do.	-25	Soft.		Hot-air pump.	do.	258
		do.	- 5	Good.	many	Hand pump.	do.	259
57		do.	-14	do.	14	Windmill.	Domestic and stock.	260
47		Granite.	-14	Soft.	many	Hand pump.	Domestic.	261
56		Complex.	- 6	Mineral.	34	Not used.	Works abandoned.	262
								263
							Domestic.	264
47		Granite.	- 3	Good.	many	Hand pump.	do.	265
							do.	266
75	34	Granite.	-35	Hard.	many	Hand pump.	do.	267
65		do.		Good.	many	do.	do.	268
117		Complex.	- 6		5			269
115	85	do.	- 4	Iron.	many	Hand pump.	Domestic.	270
60		do.	-60	do.		Windmill.	do.	271
25		do.		do.		Hand pump.	do.	272
		do.	- 34	do.		do.	do.	273
248	33, 83		-30	Soft.	10	Steam pump.	do.	274
85		Schist.		Good.		Hot-air engine.	Domestic and stock.	275
85		Complex.	-11	Soft.	7	do.	Domestic, stock and irrigation.	276
84		do.	-34	Medium.	7	do.	Domestic.	277
40		do.	-15	Hard.	many	Hand pump.	Farm.	278
		do.	- 6	Iron.		do.		279
134	16, 85	do.	-16	Hard.		do.	Domestic and stock.	280
		do.	- 5	Iron.				281
								282
84			-20	Hard.	8	Hand pump.	Domestic.	283
90	30		-39	Soft.	9	do.	Domestic and stock.	284
114	39, 77	Complex.	- 4	do.	21	do.	Domestic.	285
		do.	-15	Good.	10	Windmill and gasoline engine.	7 cottages.	286
		do.						
30	12	do.	- 6	Salty.	4	Hand pump.	Domestic.	287
		do.	- 4			do.	Stock.	288
50	20	Granite.	- 4		many	do.	Domestic.	289
100	36	Complex.	-65	Hard, iron.		do.	Hotel.	290
56		do.	- 1	Soft.	34	do.	Domestic.	291
40		Granite.			4	Abandoned.		292
38		do.	- 3	Hard.		Not used.	Too little water.	293
						Hand pump.	Domestic.	294

Records of deep wells in southern Maine—Continued.

No.	Locality.	Owner.	Year completed.	Diameter (inches).	Type.	Depth of well (feet).	Depth to rock (feet).
Lincoln County—Cont'd.							
296	Waldoboro	E. F. Genthner	1902	6	Drilled	56	4
296	do	Waldoboro Water Co	1902	6	do	156	24
297	Walpole	E. M. Woodman	1905	6	do	110	6
298	Wiscasset	Lincoln Bailey	1905	6	do	100	0
299	do	S. B. Cromwell	1904	6	do	48	0
300	do	John Dow	6	do	154	0	
301	do	W. G. Hubbard	1890	6	do	70	0
302	do	Lincoln County (jail)	6	do	154	0	
303	do	A. R. Smith	1905	6	do	80	6
304	do	J. P. Tucker	1904	6	do	50	20
305	do	Turner Center Creamery	1890	5	do	64	3
306	do	do	1905	6	do	95	0
307	do	U. S. Government (custom-house).	1905	6	do	79	24
Oxford County.							
308	North Fryeburg	L. W. Atkinson	1890	---	Drilled	115	17
309	North Norway	Charles A. Merrill	---	---	do	62	---
310	do	do	1891	---	do	102	---
311	Rumford Falls	C. M. Bishes and R. J. Virgin	1901	8, 6	do	73	20
312	do	Rumford Falls Light and Water Co.	1904	2, 3	Driven	22-35	n. r.
313	South Paris	J. Frank Howland	1890	12	Drilled	122	50
314	do	Mason Manufacturing Co.	1906	6	do	117	42
315	do	George R. Morton	1906	6	do	52	0
316	Sweden	Walter Evans	---	---	do	89	6
Penobscot County.							
317	Bangor	H. C. Chapman & Son (Bangor House).	1899	6	Drilled	290	50
318	do	City of Bangor (high school)	1906	6	do	217	---
319	do	City of Bangor (Larkin st. school).	1906	6	do	188	---
320	do	City of Bangor (Palm st. school).	1906	6	do	72	---
321	do	City of Bangor (Unionsq. school).	1906	6	do	203	---
322	do	Eastern Maine Insane Hospital	1896	6	do	425	0
323	do	Foster & Scribner	---	---	do	57	0
324	do	F. L. Jones	1905	6	do	247, 3	14
325	do	Thomas McAlloan	---	---	do	77	---
326	do	Maine Creamery Co.	---	---	do	120	50
327	do	Morse & Co.	1906	6	do	255	0
328	do	Penobscot County courthouse	1905	5	do	201	---
329	Bradford	W. E. Bailey	1882	8	Bored	54	---
330	do	J. J. Reeves	1895	8	Drilled	197	---
331	do	H. T. Williams	1885	6	do	61	---
332	Brewer	Eastern Manufacturing Co.	1899	6	do	350	59
333	do	do	1899	6	do	250	---
334	Carmel	H. W. Garland	1902	6	do	66	66
335	do	J. E. Hasey	1902	7	do	58	---
336	do	O. A. Stevens	1900	6	Bored	75	---
337	Charleston	Charles Elden	---	---	Drilled	50	10
338	do	Higgins Classical Institute	---	6	do	105	0
339	do	A. H. Mitchell	---	---	do	190	40
340	Corinna	N. Reed Packard	1904	7, 6	do	61	4
341	do	A. J. Richardson	1884	6	do	59	---
342	do	P. H. Simpson	1888	---	do	108	3
343	Corinth	L. H. Sawyer	1890	---	do	70	0
344	Dexter	James Cole	1895	6	do	58	24
345	Dixmont	E. D. Rowell	1887	6	do	112	5
346	East Corinth	Northern Maine Packing Co.	1899	6	do	465	8
347	East Newport	L. D. Babb	1887	6	do	79	0
348	do	J. B. Chadbourne	---	---	do	57	4
349	do	J. P. Chadbourne	---	---	do	63	---
350	do	C. M. Loud	1883	6	do	55	9
351	Etna	H. L. Grove	1897	6	do	54	6
352	do	G. B. Hibbard	1900	6	do	80	60
353	do	G. A. Sanborn	1890	6	do	57	50

Records of deep wells in southern Maine—Continued.

Depth to principal water supply (feet).	Depth to other supplies (feet).	Material in which water occurs.	Average height to which water rises (+ above, — below, well mouth).	Quality.	Yield (gallons per minute).	How obtained, where used.	Use, or if not used, the reason why.	No.
48	37	Granite	— 27	Soft.	5½	Hand pump	Domestic	285
150	17	do.	— 26	do.	5	Not used.	Never completed	286
106		Complex.	— 12	Hard.			Drinking and stock	287
90	35	do.	— 20	Good.		Windmill	Domestic and stock	288
		do.	— 8	Little iron	5	Hand pump	do.	289
68	18	do.	— 20	Hard.	15±	do.	Drinking and stock	300
		do.	— 20	do.		Gasoline engine	Domestic and stock	301
	15	do.	— 10	Good.		Hand pump	Drinking and stock	302
		do.	— 50	do.		do.	Domestic	303
56		do.	— 8	Salty		do.	Domestic and stock	304
		do.	— 3	Brackish		Abandoned	Salty water	305
79	72	do.	— 12	Hard.	8	Steam pump	Cooling cream	306
		do.	— 12	Hard.		Hand pump	Domestic	307
			— 17	Hard.		Windmill	Domestic and stock	308
					few	Hand pump		309
25		Granite	— 20	Soft.	few	Not used.	Too little water	310
20		Sand and gravel.	— 50		few	Steam pump	Public supply.	311
55		Complex.	— 60	Good.		Not used.	Too little water	312
40		Granite.	— 1	Soft.	40		Drinking and boilers	313
79		Complex.	— 17	Hard.		Not used.	Domestic	314
		Trap.					Strong taste.	315
								316
280	— 100	Slate	100	Hard.	27	Pump	Hotel	317
		do.		Good.	many	Hand pump	Drinking	318
		do.	— 8	do.	30	do.	do.	319
		do.		do.	many	do.	do.	320
		do.		do.	many	do.	do.	321
425	50	do.	— 200	Good, hard.	30	Steam pump	Domestic	322
247½		do.	— 22	Good.	many	Hand pump	Drinking	323
		do.	— 10	do.	many	do.	do.	324
		do.	— 10	do.	many	do.	do.	325
255	17	do.	+ 2	Soft, good.		Hand pump	Cooling cream and sold	326
60	80	do.	— 50	Hard.		Electric pump	Domestic	327
35		do.	— 19	do.		Hand pump	Drinking	328
20		do.	— 20	do.	few	do.	Public well	329
58		do.	— 15	do.	1	do.	Domestic	330
21		do.	— 21	Salty	1	do.	Domestic and stock	331
50+		do.	— 20	Hard.	1	Steam pump	Cooling acid	332
50		do.	— 16	do.	2	do.	do.	333
12		do.	— 12	Soft.	2	Hand pump	Domestic	334
50		do.	— 25	Hard.	3½	do.	do.	335
		do.					Domestic	336
100		do.	— 8		15	Siphon	Domestic for 4 buildings.	337
		do.		Good.	many			338
61	20, 30	do.	— 15	Hard.	4	Windmill	Domestic and stock	339
50		do.	— 18	do.	3	do.	Domestic	340
20		do.	— 15	Hard, salty		Abandoned	Poor water	341
20	35	do.	— 20	Soft.		Hand pump	Farm	342
53		do.	— 20	Hard.	few	do.	Domestic	343
112		do.	few	Hard, alkaline		do.	Domestic and stock	344
450		do.	— 6	Sulphur and iron.	20	Steam pump	Drinking and canning	345
								346
70	35	do.	— 15	Soft.	30	Windmill	Domestic and stock	347
		do.	— 55	Hard.			Domestic	348
		do.	— 17	do.			do.	349
		do.	— 15	Fair		Hand pump	Domestic and stock	350
50	20	do.	— 10	Soft.	15	do.	do.	351
80	50	do.	— 20	Hard.		do.	do.	352
50	41	do.	— 10	Little iron		do.	Farm	353

a Average.

Records of deep wells in southern Maine—Continued.

No.	Locality.	Owner.	Year completed.	Diameter (inches).	Type.	Depth of well (feet).	Depth to rock (feet).
<i>Penobscot County Con.</i>							
354	Hampden.....	A. J. Bragg.....	1896	7	Drilled	103	
355	do.....	Cyrus Moulton.....	1901	6	do	55	
356	do.....	C. L. Philbrick.....	1899	6	do	50	
357	do.....	J. E. Shaw.....	1899	6	do	100	
358	do.....	Village of Hampden.....	1900	5	do	123	
359	Hampden Corners.....	J. F. Maddocks.....		6	do	65	
360	do.....	J. F. Shaw.....	1896	6	do	100	
361	Hudson.....	Geo. H. Smith.....	1887	6	do	55	
362	Kenduskeag.....	Chester Weld.....		6	do	100	
363	Newport.....	Frank Bennett.....	1899	6	do	53	
364	do.....	W. D. Crowell.....	1891	6	do	75	
365	do.....	Edwin W. Trueworthy.....		6	do	100	
366	North Dixmont.....	Thos. L. Bragden.....		6	do	78	
367	do.....	S. E. Harris.....	1896	4	do	55	
368	do.....	do.....	1897	5	do	55	
369	do.....	Chas. O. Varney.....	1895	6	do	55	
370	Orono.....	N. W. Page.....	1903		Dug	54	
371	do.....	E. W. Mansfield.....	1890	6	Drilled	53	
372	do.....	University of Maine.....	1896	6	do	54	
373	Orrington.....	Archie Harding.....	1894	7	do	50	
374	Plymouth.....	H. M. Gage.....	1896	6	do	65	
375	do.....	H. W. Stackpole.....	1893	6	do	73	
376	Stetson.....	R. A. Fitts.....			do	100	
377	do.....	F. E. Wiggin.....	1878	12	do	74	
<i>Sagadahoc County.</i>							
378	Bath.....	Bath Iron Works.....	1885	4	Drilled	100	
379	do.....	George Connell.....	1887	6	do	57	
380	do.....	W. J. Donald.....	1883	6	do	167	
381	do.....	J. E. Dunton's heirs.....	1885	6	do	149	
382	do.....	C. A. Hooker.....	1893	4	do	100	
383	do.....	H. Langdon.....	1883	6	do	200	
384	do.....	Torrey Roller Bushing Works.....	1885	4	do	180	
385	Bowdoinham.....	Mrs. George L. Hinckley.....			do	124	
386	Five Islands.....	George E. Hughes.....	1900	6	do	242	
387	Georgetown.....	William Wade.....	1904	6	do	270	
388	McMahans Island.....	Sheepscot Land Co.....		6	do	240	
389	Pejepscot Mills.....	Pejepscot Paper Co.....			do	335	
390	do.....	do.....			do	40	
391	Popham Beach.....	— Tibbetts.....			do	962	
392	do.....	Fort Popham.....			do	91	
393	Richmond.....	Eugene Rankins.....	1885	5	do	72	
394	do.....	Frank Williams.....	1885		do	75	
395	Small Point.....	George O. Curtis.....	1904	6	do	100	
396	Woolwich.....	Lincoln Bailey.....	1905	6	do	98	
397	do.....	F. W. Carleton.....	1892	6	do	98	
398	do.....	J. Collins.....	1887	6	do	53	
399	do.....	George G. Hathorn.....	1897	6	do	96	
<i>Somerset County.</i>							
400	Fairfield.....	F. C. Tobey.....	1884	8	Drilled	91	
401	Norridgewock.....	F. H. Burrell.....	1901	6	do	71	
402	do.....	Guy C. Haynes.....		6	do	78	
403	Palmyra.....	Perry Furbush.....		6	do	157	
404	do.....	do.....		6	do	80	
405	do.....	do.....		6	do	80	
406	Pittsfield.....	W. R. Hunnewell.....			do	47	
407	St. Albans.....	J. L. Palmer.....	1897	8	do	40	
408	Skowhegan.....	Levi P. Weston.....	1880		do	52	
<i>Waldo County.</i>							
409	Belfast.....	W. E. Whitcomb.....		6	Drilled	81	
410	Belmont.....	Horace Cheney.....	1905	10, 8	do	187	
411	Brooks.....	Jerome Geness.....				51	

Records of deep wells in southern Maine—Continued.

Depth to principal water supply (feet).	Depth to other supplies (feet).	Material in which water occurs.	Average height to which water rises (+ above, K below, well mouth)	Quality.	Yield (gallons per minute).	How obtained, where used.	Use, or if not used, the reason why.	No.
90	40	Slate	-13	Soft		Hand pump	Domestic	354
78		do.	-5	Hard	1	do.	do.	355
30		do.	-30	Hard, iron		Pump	do.	356
95	25	do.	-20	Medium		Hand pump	do.	357
		do.		Hard	5	Not used		358
65		do.	-10		$\frac{1}{2}$	Hand pump	Drinking and stock	359
90	25	do.				do.	Domestic and stock	360
	42	do.	-48	Hard		do.	do.	361
23		do.		Iron	1	do.	Domestic	362
29		do.	-24	Soft		do.	do.	363
16		do.	-16	Hard	many	do.		364
70		do.	-25	do.		do.	Domestic and stock	365
		do.	-20	do.		do.	do.	366
55		do.	-22	do.		Windmill	Domestic	367
44		do.	-44	Poor		Hand pump	do.	368
		do.	few	Soft		do.	do.	369
30		Gravel	-30	Hard, good		Windmill	Domestic and stock	370
		Slate	-15	Hard		Hand pump	Domestic	371
52		do.	few	do.		Windmill and electric motor	do.	372
50		do.		Good	many	Hand pump	Domestic and stock	373
		do.	-30	Hard		Windmill	Farm	374
		Sand		Good		do.	Domestic and stock	375
74		Slate	-30	Poor	0 few	Not used	No water	376
						Hand pump	Stock	377
50		Gneiss	-3		4	Abandoned	City water installed	378
160		do.	-7	Soft	30	Hand pump	Domestic	379
			-30	Hard		Abandoned	City water installed	380
60	20	Gneiss	-0	do.	40	Not used	do.	381
						Steam pump	Formerly used in boilers	382
20			-20	Soft	1	Windmill	Domestic and irrigation	383
50	130	Gneiss	-20	Hard		Steam pump	Bushing works	384
		do.		do.		Not used	Pump broken	385
242		Granite	-50	Soft	few	Electric-motor pump	Domestic	386
					4			387
		Gneiss	-40	Soft				388
		do.	-24	Good	few	Hand pump	Domestic	389
				do.	many	do.	do.	390
						Not a well	Prospecting for coal	391
16		Complex	-26	Hard, iron	12	Hand pump	Domestic	392
65		do.	-3	do.	2	do.	Stock and lawn	393
79					2			394
90	35	Complex	-20	Little hard		Abandoned	Poor water	395
		Gneiss		Hard	8	Hand pump	Domestic and stock	396
50	30		-7			do.	Farm	397
		Gneiss	-30	Hard	6	do.	Domestic and stock	398
								399
		Slate	-10	Hard		Hand pump	Domestic	400
70		do.	-35			Never used	Never installed; deep-well pump	401
26		do.	-0			Siphon	Domestic and stock	402
		do.			0	Not used	No water	403
					$\frac{1}{2}$	Hand pump	Stock	404
60		do.		Hard		do.	do.	405
			-7	Soft		Not used		406
41		Slate	-8	do.	$\frac{1}{2}$	Windmill	Dairy and stock	407
		do.				Abandoned	City water installed	408
		Slate						409
		do.	-3		19	Steam pump	Domestic and stock	410
		do.						411

Records of deep wells in southern Maine—Continued.

No.	Locality.	Owner.	Year completed.	Diameter (inches).	Type.	Depth of well (feet.)	Depth to rock (feet.)
<i>Waldo County—Cont'd.</i>							
412	Cape Jellison.....	Northern Maine Seaport R. R. Co.	1905	8, 6	Drilled.....	225	70±
413	do.....	do.....	1905	6	do.....	158	90
414	East Northport.....	Mrs. Mark Mandall.....	1900	6	do.....	64	4
415	do.....	Mountain Spring Water Co.....	1900	6	do.....	168	65
416	East Troy.....	L. E. Prentiss.....	1885	8	do.....	65	25
417	Islesboro.....	E. R. Adams.....	1906	6	do.....	100	
418	do.....	John T. Atterbury.....	1902	6	do.....	150	
419	do.....	George Bird.....	1902	6	do.....	78	28
420	do.....	R. A. Boit.....	1902	6	do.....	398	
421	do.....	F. E. Bond.....	1901	6	do.....	218	4
422	do.....	H. E. Bond.....	1902	5½	do.....	218	9½
423	do.....	J. R. Brackett.....	1898	6	do.....	50±	
424	do.....	Miss Caldwell.....	1901	6	do.....	266	5½
425	do.....	Mrs. W. H. Draper.....	1899	6	do.....	165	5
426	do.....	Mrs. — Draper.....	1899	5½	do.....	102	10½
427	do.....	W. P. Farnsworth.....	1900	6	do.....	70	
428	do.....	J. Murray Forbes.....	1900	6	do.....	180	
429	do.....	D. Hatch.....	1901	6	do.....	66	13
430	do.....	F. W. Hatch.....	1902	6	do.....	63	0
431	do.....	P. D. Hatch.....	1902	6	do.....	60	8½
432	do.....	T. B. Homer.....	1892	6	do.....	120	
433	do.....	do.....	1897	6	do.....	200	
434	do.....	Islesboro Land and Improve- ment Co.	1890	6	do.....	149	5
435	do.....	— Kissel.....			do.....	220	
436	do.....	H. A. Lewis.....	1900		do.....	75	
437	do.....	M. E. Lewis.....	1903	6	do.....	150	
438	do.....	Mrs. Minton.....			do.....	300±	
439	do.....	H. W. Morse.....	1901	6	do.....	210	130
440	do.....	Leighton Parks.....	1901	5	do.....	65	
441	do.....	Charles Pendleton.....	1901	6	do.....	54	4
442	do.....	do.....			do.....	50	
443	do.....	W. S. Pendleton.....	1901	6	do.....	69	13
444	do.....	Pendleton Bros.....	1890	5½	do.....	71	12
445	do.....	C. S. Pierce.....	1901	6	do.....	225	
446	do.....	Charles Platt.....	1901	6	do.....	125	7
447	do.....	Helen L. Pratt.....	1898	8	do.....	101	
448	do.....	E. S. Preble.....			do.....	70	
449	do.....	F. C. Shattuck.....	1900		do.....	90	
450	do.....	H. T. Sloan.....	1902	7½	do.....	198	
451	do.....	David H. Smith.....	1901	6	do.....	134	0
452	do.....	Town of Islesboro.....	1887	5½	do.....	73	7½
453	do.....	J. D. Winsor.....	1902	5½	do.....	252	56
454	Jackson.....	M. S. Hatch.....	1885	9, 6	do.....	53	5
455	do.....	E. E. Morton.....	1885	7	do.....	45	6
456	Kidders Point, Searsport	Northern Maine Seaport R. R. Co.			do.....	285	62
457	Monroe.....	Nathan Stearns.....	1890	7	do.....	61	47
458	Searsport.....	J. H. Kneeland.....	1892	6	do.....	50	4
459	do.....	David Nickels.....	1904	6	do.....	108	17
460	do.....	Northern Maine Seaport R. R. Co.	1905	8, 6	do.....	329½	105
461	do.....	Penobscot Coal and Wharf Co.			do.....	301±	80
462	do.....	Searsport House.....	1894	6	do.....	97	10
463	do.....	Town of Searsport.....	1886	6	do.....	100	6
464	do.....	N. W. Staples.....	1887	6	do.....	64	34
465	Stockton Springs.....	J. C. Lambert.....	1892	6	do.....	50	15
466	do.....	Northern Maine Seaport R. R. Co.	1905	8, 6	do.....	247	74
467	do.....	A. H. Soden.....			do.....	100±	
468	Winterport.....	S. Chase.....	1888	6	do.....	57	6
469	do.....	C. W. Nealey.....		6	do.....	115	15
<i>Washington County.</i>							
470	Calais.....	F. N. Beckett.....		6		90	
471	do.....	W. A. Rideout.....	1882	5		49	49
472	Columbia Falls.....	A. H. Chandler.....	1905	4	Driven.....	46	n. r.
473	do.....	A. and R. Logie.....	1904	6	do.....	72	n. r.
474	Eastport.....	Seacoast Canning Co.....	1903	6	Drilled.....	408	0

Records of deep wells in southern Maine—Continued.

Depth to principal water supply (feet).	Depth to other supplies (feet).	Material in which water occurs.	Average height to which water rises (+ above, - below, well mouth).	Quality.	Yield (gallons per minute).	How obtained, where used.	Use, or if not used, the reason why.	No.
225		Slate	-20		200	Electric motor...	Locomotives and ships	412
158		do.			12	Abandoned	Supply insufficient.	413
		Schist	-1	Hard.			Domestic	414
112	75, 100	do.	-50	Soft.	27	Steam pump	Public supply.	415
40	52	Slate	-53	do.		Hand pump.		416
		do.			15			417
		do.		Good.	15			418
35		do.	-30	Hard.	3	Hot-air engine	Domestic	419
394	200±	do.	-15	do.	10	do.	Domestic and irrigation.	420
218		do.	-40	do.		Power pump.	Domestic	421
218		do.	-4	Medium	16	Steam pump	Domestic and stock.	422
		do.		Hard.	8	Hot-air engine	do.	423
260	55	do.	-7	Medium	14	Steam pump	Domestic	424
90		do.		Hard.		Hand pump.	do.	425
99		do.	-11	Medium	16	Gasoline engine.	do.	426
20		do.	-0	Hard.	3	Hand pump.	Stable.	427
		do.		Good.	20		Domestic	428
30		do.		Hard.	8	Gasoline engine.	do.	429
57		do.	-17	do.	4	Hot-air engine	do.	430
31		do.	-4	Soft.	1½	Pump.	do.	431
		do.	-10	Hard.	1	Steam pump	do.	432
	50	do.	-few	do.	1½	Hand pump.	do.	433
		do.		do.	8	Hot-air engine.	Hotel and 10 cottages.	434
		do.		Good.				435
		do.	-20	Hard.	4	Hot-air engine.	Domestic	436
150		do.	-8	do.	12	do.	do.	437
		do.			few			438
		do.	-50	Hard.		Hot-air engine.	Domestic	439
		do.	-3	do.	5	do.	do.	440
24		do.	-12	do.	4	do.	do.	441
		do.		Salty				442
22		do.		Iron.	6	Hand pump.	Store and mill.	443
70		do.	-5	Soft.	5	Steam pump	Gristmill.	444
		do.	-6	Hard.		Hot-air engine.	Domestic and stock.	445
120	60	do.		Soft.	14		Domestic	446
20		do.	-10	do.		Gas engine.	do.	447
		do.			many			448
		do.	-5	Hard.			Domestic	449
190		do.	+0		12	Hot-air engine.	do.	450
75		do.	-20	Hard.	10	Hand pump.	do.	451
73		do.	-12	do.	3	do.	Public well.	452
252	125	do.	+0				Domestic	453
50	25	do.	-20	Hard, iron		Windmill.	Domestic and stock.	454
	13	do.	-13	Hard.		Hand pump.	Farm.	455
284	80	do.	-16	Soft.	75	Electric power pump.	Locomotives and drinking.	456
		do.	-41	Hard, iron.		Pump.	Domestic and stock.	457
50	24	do.	-20	do.		Hand pump.	Drinking and stock.	458
	60	do.	-19	Soft.	20	do.	Domestic	459
3294		do.	-12	do.	60	Steam pump.	Locomotives	460
300		do.			50		Domestic and boilers	461
100		do.	+0	Good.		Windmill	Hotel.	462
64		do.	-8	Hard, iron.		Pump.	Public well.	463
40		do.	-24		4	Hand pump.	Domestic and stock.	464
		do.	-25			do.	do.	465
247	187	do.	-32			Steam pump.	Locomotives	466
		do.						467
53	30	do.	-30	Hard, iron.		Hand pump.	Domestic and stock.	468
115		do.	-50			do.	Stock.	469
40			few			Not used.		470
49			-20	Soft.		Pump.	Domestic.	471
		Gravel.	-12	Hard.	4	Windmill.	do.	472
68	50	do.	-20	Soft.	3	Steam pump.	Canning factory.	473
345	408	Green stone.	+0	Good, hard.	60	Gas engine.	do.	474

Records of deep wells in southern Maine—Continued.

No.	Locality.	Owner.	Year completed.	Diameter (inches).	Type.	Depth of well (feet).	Depth to rock (feet)
<i>Washington County—Continued.</i>							
475	Jonesport.....	Seacoast Canning Co.....	1904	6	Drilled.....	334	
476	Lubec.....	Lubec Sardine Co.....			do.....	165	
477	do.....	W. J. Mahlman.....	1893	6	do.....	100	
478	North Lubec.....	Seacoast Canning Co. a.....		6	do.....	60-70	
479	Pembroke.....	Gardiner Brick Co.....	1898	6.5	do.....	85	
480	do.....	Sprague & Wyllie.....		6.5	do.....	90	
481	Roque Island.....	George A. Gardiner.....			do.....	90	
<i>York County.</i>							
482	Alfred.....				Drilled.....	140	
483	Berwick.....	Benjamin Bragdon estate.....			do.....	65	
484	do.....	C. E. Marshall.....	1898	6	do.....	80	
485	Buxton.....	J. M. Hopkinson.....		6	do.....	46	
486	Cape Neddick.....	C. B. Moseley.....	1894	6	do.....	28	
487	do.....	W. H. Wentworth.....	1889	6	do.....	70	
488	Fortune Rock.....	J. G. Brackett.....	1893		do.....	97	
489	do.....	— Davis.....	1889	6	do.....	100	
490	Gerrish Island.....	S. E. Jennison.....	1898	6	do.....	58	
491	Kennebunk.....	Boston and Maine R. R.....	1892	6	do.....	120	
492	do.....	Dr. Ross.....	1893	6	do.....	100	
493	Kennebunk Beach.....	C. W. Arnold.....		6	do.....	80	
494	Kennebunkport.....	John W. Deering.....		6	do.....	50	
495	do.....	— Gilles.....	1886	6	do.....	75	
496	do.....	— Hall.....	1886	6	do.....	75	
497	do.....	Kennebunkport Seashore Co.....	1889	6	do.....	55	
498	do.....	— Smith.....	1885	6	do.....	60	
499	do.....	B. S. Thompson.....	1885	6	do.....	70	
500	Kittery.....	U. S. Government (navy-yard).....			do.....	200	
501	do.....	do.....			do.....	300	
502	Kittery Point.....	Horace Mitchell.....		6	do.....	60	
503	do.....	Pepperell House.....		6	do.....	51	
504	do.....	John Thaxter.....	1887	6	do.....	125	
505	do.....	Roland Thaxter.....			do.....	75	
506	Lebanon Center.....	N. B. Shapleigh.....	1893	6	do.....	50	
507	Limerick.....				do.....	100	
508	North Berwick.....	A. P. Littlefield.....			do.....	125	
509	Ocean Bluff.....	Arlington Hotel.....			do.....	50+	
510	do.....	Sarah Bancroft.....	1884	6	do.....	73	
511	do.....	Mrs. Samuel H. Jones.....			do.....	224	
512	do.....	Kennebunkport Seashore Co.....			do.....	85	
513	do.....	Ocean Bluff House.....			do.....	102	
514	Ogunquit.....	Edward Freeman.....			do.....	68	
515	do.....	Charles C. Hoyt estate.....	1890	6	do.....	65	
516	Saco.....	City of Saco.....	1886	6	do.....	250	
517	do.....	Mason & Durgin.....		8	do.....	56	n. r.
518	do.....	W. Warren (?).....			do.....	61	n. r.
519	Wells.....	A. P. Littlefield.....			Drilled.....	100	
520	York.....	Hugh Talant.....		6	do.....	90	
521	York Beach.....	Dr. Clement.....			do.....	59	
522	do.....	C. W. Hildreth.....		6	do.....	60	
523	do.....	C. B. and W. C. Hildreth.....	1891		do.....	60	
524	do.....	York Beach Water Co.....		6	do.....	60	
525	York Harbor.....	E. S. Marshall.....	1888	6	do.....	325	
526	do.....	York Harbor Hotel.....	1888	6	do.....	150	

a Three wells.

Records of deep wells in southern Maine—Continued.

Depth to principal water supply (feet).	Depth to other supplies (feet).	Material in which water occurs.	Average height to which water rises (+ above — below well mouth).	Quality.	Yield (gallons per minute).	How obtained, where used.	Use, or if not used, the reason why.	No.
96		Diorite.	- 7	Hard.	2½	Hand pump.	Drinking.	475
		Greenstone.	-12	Good.	0	Not used.	Very little water.	476
		do.	- 1	do.	1	Abandoned.	City water installed.	477
		do.		do.		Windmill.	Canning factory.	478
				Good.				479
				do.		Gasoline engine.	Domestic.	480
								481
39			-34			Not used.		482
65		Slate.	-12	Poor.	many	Abandoned.	City water installed.	483
		do.	+ 0			do.	do.	484
42	30		-24	Hard.	few		Domestic.	485
27		Slate.	+ 0	Soft.	30	Pump.		486
		do.	+ 2½	do.		Windmill.	Supplies 25 families.	487
97		Granite.	-20			do.	Domestic.	488
100	95				few		do.	489
56	30	Slate.	- 6	Soft.	5		do.	490
120			- 3		24		do.	491
100±		Granite.	-20		10			492
			-10		few	Not used.	City water installed.	493
						Hand pump.	Domestic.	494
								495
50				Soft.	3	Not used.	City water installed.	496
					few		Domestic.	497
					few		do.	498
		Slate.			0	Not used.	Nearly dry.	499
					15			500
15		Slate.	- 7½	Soft.	1	Windmill.	Hotel.	501
		do.	- 5	do.		Not used.	Hotel abandoned.	502
110		Trap.	-14	Hard.	½	do.	Too little water.	503
		Slate.		Iron.		Hand pump.	Domestic and stock.	504
45		do.	-40	Hard, iron.	1	do.	Domestic.	505
				Surface water.				506
122		Granite.	-10	Soft.	few		Stock.	507
		Slate.				Abandoned.	City water installed.	508
224	90			Iron.	8	do.	do.	509
		do.			few	do.	do.	510
		do.				do.	Hotel burned.	511
65		Granite.			few	do.	Failure.	512
65		Slate.	- 5	Hard.	10+			513
						Hot-air engine.	Domestic, stock, and boilers.	514
250		do.	-20		10	Windmill.	Fountains.	515
56		Gravel.	+ 0			Abandoned.		516
		do.	+ 0					517
50		Granite.						518
89½		Slate.		Brackish.	5	Not used.	City water installed.	519
		Granite.	+ 0		40	Pump.		520
60		do.	-14	Hard.	few	Hand pump.	Domestic and stock.	521
60		Slate.	-18	do.		Windmill.	do.	522
325		Granite.	+ 2		84	Abandoned.		523
		Slate.	-30	Salty.	16	Not used.	Too salty.	524
						do.	Not enough for hotel.	525
								526

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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

WATER-SUPPLY PAPER 224

SOME DESERT WATERING PLACES
IN
SOUTHEASTERN CALIFORNIA AND
SOUTHWESTERN NEVADA

BY
WALTER C. MENDENHALL



WASHINGTON
GOVERNMENT PRINTING OFFICE
1909

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SOME DESERT WATERING PLACES IN SOUTHEASTERN CALIFORNIA AND SOUTHWESTERN NEVADA.

By WALTER C. MENDENHALL.

INTRODUCTION.

AREA CONSIDERED.

This report relates especially to the southwestern part of the Great Basin—the portion of it that is bounded on the west by the Sierra Nevada and Sierra Madre, on the east by Colorado River, on the south by Mexico, and on the north by the parallel between Tps. 4 and 5 S. of the Mount Diablo base line. It includes the arid portions of southeastern California and those adjacent parts of Nevada that are most easily reached from California points. This region is known generally to the dwellers in the less arid districts west of the Sierra as “the desert,” but local names are applied to its various subdivisions. Among the more important of the subdivisions are the Colorado and Mohave deserts and the Death Valley region.

The Colorado Desert is that definitely limited arid valley which extends from San Geronimo Pass southward to the Gulf of California, and includes the depression known as the “Salton Sink.” The Mohave Desert lies farther north and its boundaries are not so definite, but it includes much the greater part of San Bernardino County and the eastern portions of Los Angeles and Kern counties, Cal. The Death Valley region, which lies north of the Mohave Desert, stretches eastward from the Sierra Nevada, covering a large part of Inyo County, Cal., and extending into Nevada. It is named from its central feature, Death Valley, the lowest point on the continent.

The desert region outlined above and shown on the accompanying map (Pl. I) covers an area of about 68,000 square miles. The wells and springs within it are few in number and are very irregularly distributed. In some districts watering places occur in groups; in other tracts they are 30 to 50 miles apart. So irregular is their distribution that it is important that they should be located as definitely as possible and described for the benefit of prospectors and other travelers. The scarcity of water and the importance of a knowledge

of its whereabouts are indicated by its cost in many of the mining camps and by the frequency with which the press records instances of death from thirst in the more remote parts of the desert.

MINERAL RESOURCES AND INDUSTRIAL DEVELOPMENTS.

The mineral resources of the region under discussion are being developed with a rapidity that is attracting general attention. The most important of these resources is gold, and the present intense interest in the desert is in large part due to the discovery and development within it of mines that are heavy producers of this metal.

The resources of the region, however, are not confined to the precious metals, but comprise a wide range of mineral products of economic value. Among these may be mentioned several valuable salts, including borax, soda, gypsum, and common salt; building material, including marble, onyx, brick clays, and cements; baser metals, like copper, iron, and lead; and gems, among which are turquoise and opal. Just west of the desert proper, in the mountains of San Diego and Riverside counties, precious tourmaline, kunzite, and the rarer garnets have been discovered in connection with the pegmatite dikes there. These products are widely distributed throughout the desert counties. The existence of some of them in commercial quantities and available form is as yet problematic, although their occurrence is known, while important industries are already based on others.

The building of railroads in the desert within the last three years and the projection of other lines not yet built indicate for the future a marked increase in the mineral output of this region. The Atchison, Topeka and Santa Fe Railway, generally known in the West as the Santa Fe, has one branch extending from Goffs, on its main line, northward to Ivanpah, a distance of about 50 miles; another from Ludlow southward 7 miles to Stedman; and a third running northward from Kramer to the mining camps at Randsburg and Johannesburg, a distance of 25 miles. A road has also been built from Ludlow to Bullfrog, Nev., with a branch to the Lila C. borax mines.

The Santa Fe is also constructing a road from Wickenburg, Ariz., to Parker, on Colorado River, and thence to Bengal, Cal., on the main line. This particular work is intended to correct the alignment of the transcontinental line, and to reduce grades and shorten the distance between Los Angeles and Chicago.

The San Pedro, Los Angeles and Salt Lake Railroad has completed a road from Las Vegas, Nev., to Bullfrog and Goldfield, Nev. Its main line is in operation from Daggett northeastward across the intervening deserts to Ogden, Utah, and is giving active stimulus to gold, silver, and lead mining. The Southern Pacific has a branch on the Colorado Desert, running from Imperial Junction southward

to the Imperial Irrigation Colony lands, and across the boundary into Mexico.

A line is being built that will unite the Southern Pacific branch at Keeler, on the east side of Owens Lake, with Mohave, near the southern edge of the Mohave Desert. Other lines are also projected which, if constructed, will connect Bullfrog directly with Los Angeles.

This unusual activity in railroad work, due in part to recent mining developments, has so stimulated prospecting that there is a large influx of strangers, many of whom do not fully realize the danger of traveling through an arid region in which springs are few and far between. The dissemination of information concerning the locations of known watering places and the possibilities for locating and developing water at other favorable points is therefore an urgent need. To meet this need the following report has been written and the map that accompanies it has been prepared.

SOURCES OF DATA.

The larger part of these data was compiled by Gilbert E. Bailey, who for several years has been obliged to traverse repeatedly many of the main desert roads and trails. At the outset of each trip it has been necessary to select, so far as possible, lines of travel along which water could be found, and to decide on springs that would be suitable sites for camps from which to penetrate the surrounding region.

It was not originally expected that the data thus slowly accumulated for personal use would be assembled for publication. The records are therefore by no means complete, nor are they of uniform value, for Mr. Bailey's acquaintance with some districts in the desert is more intimate than with others. Knowledge of watering places in this region is vital, and it is hoped that even the incomplete information assembled in the following pages will be useful.

In making the generalized base map (Pl. I) on which the location of the wells and springs is shown, data differing greatly in value and accuracy have of necessity been used. For the region from Death Valley northward and for the southwestern part of the area, including the Colorado Desert, the later topographic sheets of the United States Geological Survey are available and furnish satisfactory data. For the area along Colorado River from Needles northward old reconnaissance maps issued by the Survey were utilized. Of the region from the Colorado Desert and the Sierra Madre northward to Death Valley no satisfactory surveys have been made, and dependence has necessarily been placed on Land Office maps, railway surveys, and the various general, more or less inaccurate maps that have appeared from time to time. Probably the best of these—certainly

the one which is most highly regarded by prospectors and desert travelers generally—is the Fred T. Perris map of Riverside and San Bernardino counties. With such corrections as it has been found possible to make upon it, this map has been largely followed. In the desert portions of Riverside County especially, for which almost the latest data exist, the Perris map is still the best guide. Developments, especially railroad surveys and construction, have given the information necessary for some changes in the northern portion of the area covered by it.

A number of the principal roads through the desert are indicated on the map. They are not surveyed, so that only approximate locations are possible, but these at least indicate the usual routes of travel.

The descriptions of the springs and watering places have been taken largely from the notes of Mr. Bailey. A large proportion of them have been visited at various times, but descriptions of others have been supplied by other desert travelers. R. H. Chapman, topographer, United States Geological Survey, has supplied notes on a number of wells and springs in the Amargosa district, with which he is familiar; C. A. Pinkham has aided with information concerning the Colorado Desert region; C. S. Alverson, of San Diego, has also contributed notes on this area; and many miners and prospectors have supplied information with which it is not possible to credit them individually.

On the whole, it is believed that fairly adequate and accurate descriptions are given of most of the better known and more accessible springs and wells, and that many of those which are less well known are included. Of course, numbers of springs exist in the higher mountain ranges of the desert that are known only to prospectors who are familiar with the details of these ranges. These watering places, however, are inaccessible to the casual traveler. The valley wells and springs, or at least those accessible from the most used highways, are the ones on which he must depend. It is hoped that the greater number of these are described in the succeeding pages. The data will be found more complete for the northern than the southern part of the region mapped (Pl. I).

PHYSICAL FEATURES.

GENERAL CHARACTER OF THE REGION.

The arid region lying between Colorado River and the Sierra of California shows a marked contrast in nearly all its physical conditions and scenic features with the region lying west of the great range.

To the geographer the most striking characteristic of the country east of the base of the Sierra Nevada is the fact that it is a region of

interior drainage. For this reason it is known as the "Great Basin." No streams that rise within it carry contributions to the ocean, but all the snow and rain that falls inside the rim of the basin is returned to the atmosphere by evaporation, either directly from the soil or after it has found its way into some of the lakes or sinks that occupy depressions in the irregular surface.

Some of the valleys or plains that separate the mountain ranges are absolute deserts, totally destitute of water, and treeless for a space representing many days' journey, the gray sagebrush alone giving life to the landscape. Each of the main desert basins includes a large area in which the land slopes toward a central depression, and each has a main drainage way through which flows an intermittent stream whose bed is dry most of the time along the greater portion of its course.

Many of the valleys have in their lowest depressions playas, or mud plains, left by the evaporation of intermittent lakes, and some of these are of great extent. Portions of some of the valleys have become incrustated to a depth of several inches with alkaline salts, which cover the surface as an efflorescence and present the appearance of drifting snow. Most of the permanent lakes into which some of the surface drainage finds its way are saline and alkaline. Their shores are desert wastes, shunned by animals and by all forms of life except salt-loving plants. The floor of the desert is dotted with many other smaller sinks or depressions that have no outlet and no inflow except during the rare desert storms. These are known locally as "dry lakes," "borax lakes," "salt lakes," "alkali marshes," etc.

DEATH VALLEY BASIN.

Death Valley Basin (Pl. II, *A*) is the sink of the Amargosa (Spanish for "bitter"), a name that was given to the river by Gen. J. C. Frémont in 1844. This stream, which is dry for the greater part of the time throughout much of its course, rises in a group of springs that lie about 17 miles northeast of the town of Bullfrog, Nev., in Oasis Valley. Its course is a little east of south until it passes Franklin Dry Lake; thence it flows southward through a deep canyon into South Death Valley. There it turns to the west and north, and is finally lost near Saratoga Springs. The Amargosa is about 140 miles long. It repeatedly disappears and reappears, flowing a short distance and then sinking, its water being absorbed by the sands until its channel crosses a ledge of bed rock, when it again emerges to view. Its water, which is potable near its source, percolates slowly downstream through the sands and takes up increasing quantities of alkaline salts from the soil, so that when it comes to the surface along its lower course, the water is charged with these salts, and though to

the eye it may appear potable, is unsafe to drink. This condition prevails only along the middle and lower courses of the stream. It is worse during flood periods, when quantities of surface alkali from along the banks of the stream are taken into solution. Near its source, where the water first rises in the springs, it is of excellent quality.

In going toward any point of the compass from Death Valley it is found that the floor of the basin gradually rises. In traveling southward one passes over low divides and gradually descends to Soda Lake, the sink of Mohave River. From Soda Lake the ground rises toward the east to the New York Mountains. Beyond these the drainage is toward Colorado River. West of Death Valley, the floor of the desert, above which several high ranges stand, gradually rises to the foot of the Sierra Nevada.

SODA LAKE.

Soda Lake is the sink of Mohave River, which rises in the San Bernardino Mountains and flows to Barstow, and thence northeastward to this sink. The river is over 100 miles long, but except during the flood season there is little surface flow save where ledges of rock athwart its course force the water to the surface.

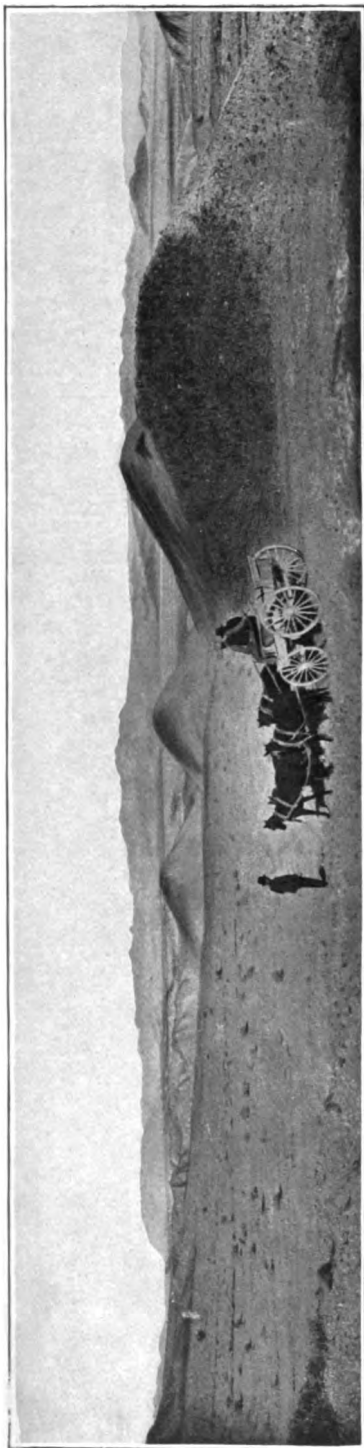
SALTON SINK.

The Salton Sink, the lowest point of the Colorado Desert, was a part of the Gulf of California in comparatively recent geologic time, but it has been separated from the present gulf by the growth of the delta of Colorado River. Normally it receives only the occasional overflow from distributaries of this river, but in 1904 the Colorado was largely diverted to it, and only recently (1907) has that river been confined to its proper channel. The sink, therefore, is now partially filled by a lake with an area of nearly 500 square miles, which will probably not dry away completely for fifteen or twenty years.

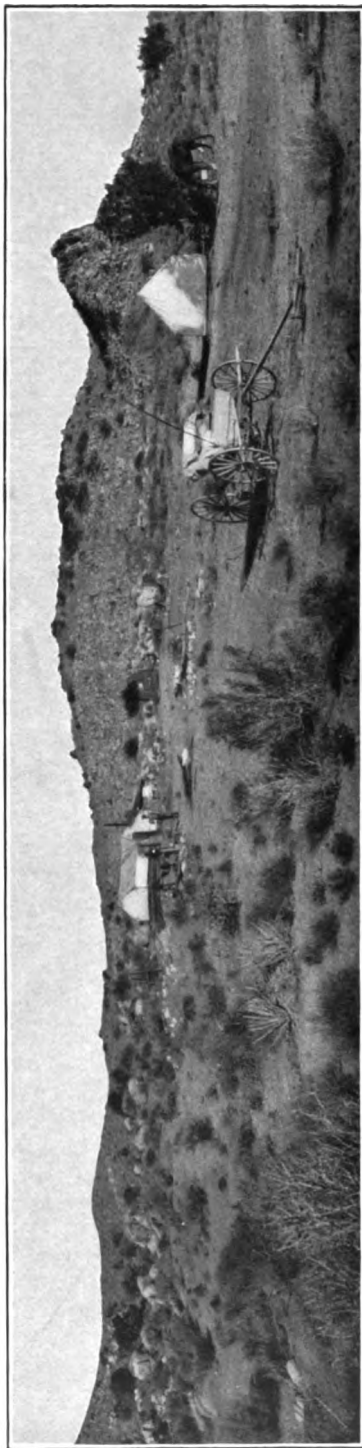
A GREAT TROUGH.

The most important sinks of the desert form a more or less continuous group along a northwest-southeast line, which may be spoken of as the Great Trough.

The Death Valley axis is about 150 miles long, and extends from the north end of the valley southeastward to Silurian Dry Lake. There begins the sink of the Mohave Basin, which extends southward through Soda Lake and the Devil's Playground to Bristol, Cadiz, and Danby dry lakes, a distance of over 125 miles. It is separated from the Death Valley trough only by the low divide between Silurian Lake and Silver Lake, which are less than 15 miles apart.



A. DEATH VALLEY, LOOKING NORTH TOWARD THE BLACK MOUNTAINS.



B. OUT WEST WELL.

The trough of the Colorado Desert extends from San Geronio Pass southeastward through the Salton Sink to the Gulf of California. It is separated from the Mohave Basin by the San Bernardino, Cottonwood, Chuckwalla, and Chocolate mountains, and so forms an overlapping parallel axis of depression. This great axis is known to be closely related to widely extended geologic structures, and it is probable that the Death Valley axis has been similarly determined.

In addition to these major controlling depressions, the entire desert area consists of a series of more or less nearly parallel ranges and intervening minor desert valleys. In the northern part of the area the trend of these features is nearly north and south, and in the southern part the trend swings to the southeast; but in the intermediate region there is an area of confused, broken ranges in which definite trends seem to be lacking.

FAULT LINES.

It is well known that the eastern front of the Sierra Nevada is a great fault scarp, but it is perhaps less generally known that the north face of the San Gabriel Mountains is a similar structural line, which extends southeastward through Cajon and San Geronio passes and into the Colorado Desert. It is regarded as probable, too, that the great trough which has been described as extending northwest and southeast through the desert, along the line of the greater sinks, owes its origin to crustal movement. The basin-range type of structure, the tilted block first recognized by Gilbert, involves faulting along the uplifted edge, and recent geologic work in the desert has proven the existence of much faulting of the block type in the Bullfrog district.^a It is not unlikely that when structural details shall have been worked out many of the strongest of the desert springs will be found along these fault lines, and that their waters will prove to be of deep origin and independent of local rainfall and local drainage. It is difficult otherwise to account for many of the springs.

CLIMATE.

The physical feature that exercises the greatest control over the climate of the Southwest is the great Sierra, which gives rain to the lands that lie west of it and withholds it from the desert to the east. The winds, which are moist and cool along the coast, shed their moisture upon the high mountains, and are dry when they reach the interior, where they absorb moisture from both the soil and the vegetation.

^a Bull. U. S. Geol. Survey No. 303, 1907, pp. 50-52.

The climatic characteristics of the desert are its excessive summer heat and its dryness. The temperature rises occasionally to 125° F in the shade, rarely falls below 70° at any time during the five hot months, and will average over 90° during this period. Exceptionally in the lowest points, as at Salton and in Death Valley, the shade temperature reaches 129° or 130°. During these periods of excessive heat men exposed to the sun's rays without water quickly perish.

The air is usually not stagnant, but is in active motion. Gales of a few hours' duration are common, and some of them bring sand storms. Rain may fall frequently in the mountains and occasionally in the valleys, and clouds are by no means rare, yet the heat and the wind together keep the surface very dry and the relative humidity low.

Cloud-bursts—concentrated storms of great severity—sometimes take place suddenly in the mountains, in the hottest weather. A cloud may form about a peak, quickly grow dense and black, and give a terrifying electric display. The lightning is followed by a torrent of rain, the character of the resulting flood depending on the relation of the storm to the topography. If it is concentrated in a canyon the result is a violent and spectacular flood wave, of great erosive and transporting power. If it is spread over an open slope, a slower moving and less destructive sheet flood follows the rain. Practically all of the desert erosion is accomplished during brief storms of this kind. Passengers on the railroads through New Mexico, Arizona, and eastern California have occasionally had experience with these cloud-bursts, and have appreciated the force and violence of the floods that result.

At a few points on the desert meteorological observations are made by volunteer observers for the United States Weather Bureau. The following tables will give an idea of the annual temperature and rainfall at a number of widely scattered points.

Temperature at 10 stations in California.

	1903. ^a			1904. ^b			1905. ^c		
	Annual mean.	Maximum.	Minimum.	Annual mean.	Maximum.	Minimum.	Annual mean.	Maximum.	Minimum.
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
Bagdad.....	72.6	113	25	71.6	110	30	.....	119	30
Barstow.....	62.4	110	24	66.8	109	30	65.2	111	28
Bishop.....	55.1	98	4	56.1	97	12	55.0	99	2
Imperial.....	74.6	124	26	.....	115	28	71.5	124	2
Indio.....	.....	118	28	.....	.....	.....	.....	125	30
Keeler.....	64.2	110	14	64.6	112	23	61.8	112	17
Mohave.....	62.7	106	15	67.6	107	23	66.2	114	3
Needles.....	.....	.....	.....	75.7	111	35	57.3	114	3
Palm Springs.....	70.4	117	32	75.6	113	32	70.4	122	2
Volcano.....	74.6	120	25	73.1	117	22	73.6	123	24

^a California section of the climate and crop service of the Weather Bureau, annual summary, 1903, pp. 8-9.

^b Idem, 1904, pp. 8-9.

^c Idem, 1905, pp. 8-9.

Rainfall, in inches, at 10 stations in California.

	Mean annual. ^a		Annual 1903. ^b	Annual 1904. ^c	Annual 1905. ^d
	Years in- cluded.	Amount.			
Bagdad.....			2.32	2.30	9.90
Barstow.....			2.66	0.80	6.40
Bishop.....	1884-1900	4.27	1.56	7.61	5.19
Imperial.....			0.34		10.06
Indio.....	1878-1900	2.43			
Keeler.....	1884-1900	2.76	0.10	3.50	6.90
Mohave.....	1877-1900	4.79	1.87	2.86	6.45
Needles.....	1892-1900	2.79		1.24	11.36
Palm Springs.....	1889-1900	3.53	0.70		9.36
Volcano.....	1899-1900	1.70	0.20	1.90	6.18

^a Monthly Weather Review, vol. 30, No. 4, April, 1902, pp. 208-209.

^b California section of the Climate and Crop Service of the Weather Bureau, *Annual Summary*, 1903, pp. 16-17.

^c *Idem*, 1904, pp. 16-17.

^d *Idem*, 1905, pp. 16-17.

The average rainfall for six years at Bishop, Inyo County, was 3.64 inches; at Camp Cady, on Mohave River, an average of 3.08 inches for two years is recorded. Daggett, San Bernardino County, had an average of 4 inches for three years. At Yuma, Ariz., a twenty-eight year record gives an average of 3.16 inches. It is probably safe to say that the normal rainfall for the desert is between 3 and 4 inches annually, but this average is derived from annual extremes ranging from seasons of no rainfall to those having as much as 10 inches.

WATER SUPPLY.

ORIGIN.

A portion of the rainfall in this region is carried off by evaporation as soon as it falls; another portion soon sinks and joins the ground water, which permanently saturates the rocks below a certain level; still another portion finds its way directly to the streams, which carry it to sinks or lakes to be again evaporated. The moisture that has been evaporated from the surface of the Pacific to float inland as vapor and be condensed again to water the earth is the original source from which practically all of the meager supply of the desert comes, but this does not mean that each spring is dependent on the rainfall in the region immediately around it. Many of the springs of the desert are of deep origin and are not fed by local rains, and the waters that supply them fall on mountains far from the points where they issue.

RIVERS.

Only four of the streams that flow toward the Great Basin from the Sierra Nevada and Sierra Madre extend beyond the base of the mountains. The others sink at once into the sands of the desert.

The waters of Owens River, which heads in the Sierra Nevada north of Mount Whitney, have been secured in part by Los Angeles, and are to be conducted across the desert to supply that city and the surrounding region with pure mountain water. For years a part of the waters that feed this river have been utilized on the fields of stockmen and farmers along its course, but the greater portion has been wasted in Owens Lake, a soda lake that has no outlet.

Amargosa River rises in springs in the mountains northeast of Bullfrog and flows southward intermittently across the desert through Franklin Lake to Resting Springs Dry Lake. On leaving this lake it enters a canyon, about 10 miles long, between Black and Kingston mountains. From this canyon it emerges into the south end of Death Valley and turns westward to Saratoga Springs, whence it flows northwestward to the sink of Death Valley. The north end of Death Valley lies nearly due west of the head of this river, so that the depression as a whole has the form of a long and narrow U. Ordinarily there is water at only a few places along the Amargosa channel, but when a cloud-burst occurs within its drainage area it may become for a few hours a raging torrent. At Resting Springs Dry Lake the stream at such a time has been over a mile wide and several feet deep. But since 1850 the river has not been known to carry enough water to flow on the surface as far as the lowest depression of Death Valley; and in its heaviest floods it rarely extends more than 4 or 5 miles below Saratoga Springs.

The waters of the Amargosa are briny along its lower course. Where it widens out into the large playa at Resting Springs Dry Lake it leaves fields of salt as well as of borax and niter. The desert for many miles on either side of the river is dotted with spots and patches of salt. Hot springs discharge into it at a number of places.

A dry wash marks the channel of the South Amargosa, which rises in Silurian Dry Lake, at the east end of the Avawatz Mountains, and runs northward to Salt Spring. Here it turns northwestward and joins the main river in South Death Valley, a few miles east of Saratoga Springs.

Mohave River rises in the San Bernardino Mountains and flows northward. The Santa Fe Railway follows approximately its course to Daggett. There the river turns northeastward and is followed by the line of the San Pedro, Los Angeles and Salt Lake Railroad until it passes through the canyon at the Caves. East of this canyon it sinks finally in Soda Lake. The divide between Silver Lake, in the Mohave drainage basin, and Silurian Dry Lake, the source of the South Fork of the Amargosa, is but 30 feet high, and consists only of sand. Thus the two river systems are separated by a very low and frail barrier.

Soda Lake, into which the Mohave finally disappears, is known also as Mohave Sink. During the wet season the waters of this lake range from a solution approaching saturation to one containing but 282 parts of solids in 100,000. In the dry season the greater part of the depression is covered with a heavy mineral crust, rich in various salts.

New River rises in Mexico, on the delta of Colorado River, whose overflow waters feed it, and flows northward into the Salton Sink. Other channels across the Colorado Desert have a similar origin and direction. One of these is Salton or Alamo River, which is almost equal in importance to New River. Salton Sink is normally a salt-incrusted depression, whose lowest point is $273\frac{1}{2}$ feet below sea level. For years it was the source of supply of salt for the New Liverpool Salt Company, but it now contains a lake, caused by diversion of the waters of the Colorado to it through the New and Salton channels.

SPRINGS.

In the higher mountains of the desert there are many "hillside" springs, whose source is the rainfall of the immediate neighborhood, but many of these springs are not permanent and are not to be depended on by travelers.

The greater permanent springs are deep seated and many of them probably lie along fault lines. Among the springs of this type whose flow seems to be too strong to be accounted for by local rainfall are those at Pahrump, Manse, and Saratoga.

Probably because of the depth to which the waters of these springs descend during their long subterranean passage, and the heat and pressure to which they are subject, they become active solvents of mineral matter, and issue along the fractures as heated springs, carrying a large percentage of solids in solution.

The waters of many of the desert springs presumably possess valuable therapeutic qualities, and complete quantitative analyses of them are warranted. Other springs furnish only ordinarily wholesome waters, that have acquired a local reputation for the treatment of disease. "Poison springs," said to contain arsenic, have been reported from many parts of the desert. The writer has examined the waters of several of these, but has failed to find any arsenic or similar poison, though he has found large quantities of sulphate of soda (Glaubers salt) and some sulphate of magnesia (Epsom salts). Salt Spring, in South Death Valley, is of this character, and prospectors are known to have perished there, so that the spring is called "poison" by many, but it contains only sodium and magnesium salts, and no arsenic or copper.

The intense heat of the summer, the exhausted condition of the famished prospector, and the abundance of these harmful salts in the waters are sufficient explanation of the deaths that have occurred. Such waters are dangerous to a hearty, healthy man who uses them with the greatest moderation, and they may be quickly fatal to the thirst-tormented sufferer who drinks them without restraint.

FINDING WATER.

CAMPING PLACES.

Many of the springs and wells in the desert may be located without special description, particularly those that are near a main route of travel. Prospectors and mine owners usually enter the field each fall to do assessment work on their mining claims. On these journeys they follow well-established roads or trails and so plan the trip as to stop at the springs where they will find the best water. As fuel is scarce, the ground in the immediate vicinity of the springs is usually so thoroughly cleared of brush as to be practically bare. Near these permanent and well-known springs, piles of tin cans and other *débris* left by campers are always to be seen. Where the location of such springs is sufficiently obvious, no detailed description of the surroundings is given in the following pages.

The traveler who is unacquainted with the route over which he is journeying should stop at places where the ground has been cleared of brush and where there is other ample evidence of the presence of many visitors, and satisfy himself as to the nature of the camp. It may be a "dry camp," such as are made on long stretches between springs, or there may be a spring or well in the vicinity, which is covered over to keep out animals, and is hidden by drifting sand. Experienced men will have no difficulty in quickly determining the nature of the camp. An inexperienced traveler should not enter the desert alone. If he can not find an experienced companion, he should proceed with the greatest caution, gathering all possible information about his route in advance, keeping himself abundantly supplied with water and food, and never leaving one water station without a definite idea as to the location of the next.

A traveler can rarely see exactly where water is to be found, except by going over the camp ground and looking carefully for wells. Many of the wells are mere shafts, 20 to 40 feet deep, rectangular in shape and covered with a few boards, which may in turn be buried by drifting sand. Only a few wells are equipped with a windlass or pump. These conveniences, even if originally supplied, quickly disappear as fuel for some traveler in need on a cold winter night. He uses them to maintain his camp fire, justifying himself in the belief that self-preservation is the first law.

Prospectors and mine owners often wish to find water in new districts, away from the main lines of travel. In their search for it they must be guided by geologic and topographic conditions and by the vegetation, which is often a useful guide.

MOUNTAIN SPRINGS AND TANKS.

As a rule the water found at high elevations comes from rocks free from alkalies and is pure and sweet. In hunting for these higher springs one must go up to the bare, rocky gulches, above the loose material into which the rain waters sink so readily and are lost. The mountain springs are small and the majority of them disappear during the drier periods, but for a short time after a storm they may be abundant and furnish strong flows.

In the lava or granite ranges water from the winter rains often collects in rock bowls. Where these are in the shade and are protected from the wind, water may remain in them for months after a storm. Such natural reservoirs are known as "tanks." After rains they may be valuable sources of supply for prospectors, but after a series of long, dry seasons they are not to be depended on. Some of these tanks are of large capacity and are very valuable to mining camps. They are so rare, however, that travelers can not expect to find them in an emergency without knowing their whereabouts or their character.

DRY LAKES.

In the vicinity of the dry lakes—the sinks of the desert—water may generally be found by digging or boring wells. These playas are the lowest points in local drainage basins. When the rains in such a drainage basin are heavy enough to induce a surface flow to the depression the waters collect there to sink gradually or to be evaporated. These sinks have no surface outlet, and some of them are rock-floored and have no underground outlet. All of the surplus water of the local watershed is, therefore, impounded in them. Although it may not accumulate at the surface, its quantity is usually sufficient so that comparatively shallow digging will reveal its presence. The supply in such a basin does not depend entirely on the amount of water that reaches the depression over the surface. An important percentage of the lighter rains is absorbed by the débris along the flanks of the desert ranges and percolates slowly through the sand and gravel to the playa. A part of the floods resulting from the rare cloud-bursts and heavier storms is also absorbed in the same way and seeks the lowest point in the basin by passage underground through the pores of the gravel.

These accumulated waters may usually be developed by the mining community or by the prospector who wishes to establish a permanent camp. The favorable place for undertaking such development, however, is not in the mud flat—the playa itself—but around its borders. All flowing and percolating waters dissolve alkalies from the rocks, sands, and gravels over and through which they flow. At the point where the waters are evaporated these salts are left behind as saline deposits. As the bottoms of these sinks are merely great evaporating pans, accumulated surface waters and rising subterranean waters both passing into the air there, they are almost invariably alkaline, and usually the alkalies extend to considerable depths. The waters in the center of the sink are impregnated with these salts and are generally not usable. But as the ground waters always percolate toward the lowest point, the waters found about the borders and at short distances back from the playa are relatively pure, since they have not yet entered the highly alkaline area. To reach the water plane at these points about the borders of the sink it may be necessary to penetrate to a greater depth than would be required nearer its center, but usually this is the only way in which potable waters can be developed at such places.

GEOLOGIC HINTS.

As already stated, pure water may be found in springs, pools, and tanks in the areas of granite, lava, or other compact rock. The favorable time to find such water is immediately after the rains or snows of winter. Many of these springs and pools are short-lived, but they furnish water of the best quality, and even immediately after rains no water can be found in the desert valleys, for their sands and gravels absorb the rain as fast as it falls.

Many inquiries are made as to the value of tunneling along a crevice from which a slight seepage escapes, in order to develop a greater supply. Of course it is well to clean out the opening from which the water comes, so that it may flow freely, and to go deep enough to see that none escapes by side channels, but more extensive development work is usually disappointing. If the water of the spring is derived from a saturated body of gravel, tunneling will result in a temporary increase of flow, as the drainage of the gravel body is improved. But in rock even a temporary increase is often not procured, so that there is no return for the expense. A bed-rock tunnel to develop water in arid regions is in the majority of cases a failure. The experience of miners in developing their prospects shows that most of the tunnels that are run into the desert mountains are dry, at least until they have been driven a great distance, and that they develop water only under exceptional conditions.

Next to unconsolidated deposits, the rocks that present the conditions most favorable for direct absorption are uncemented sandstones and certain porous limestones. In granites, slates, and other compact rocks the direct absorption is very slight.

Sandstone is on the whole the best water-bearer among the solid rocks. Under the most favorable conditions the rock is saturated throughout its extent below the regular ground-water level, and water is yielded wherever the sandstone is struck by the drill below this limit.

Conglomerates sometimes furnish water in considerable quantity, although as a rule their absorptive capacity is not so great as that of sandstones, and they are much less commonly encountered.

Sands and gravels are very porous, the free space between the grains occupying from 30 to 40 per cent of the total volume. A mass of such materials is saturated below the permanent water level, and when penetrated by wells yields copious supplies. The waters are generally of good quality, but are at some places mineralized, the mineral matter being derived from the more soluble fragments and particles of the deposits.

Clay is very impervious to water, and usually contains little or none that can be utilized as a source of supply. The water that is frequently reported in clays usually comes from layers that are more or less sandy. Some sands which approach clay in fineness, and which are at times mistaken for it, yield considerable amounts of water. Clay is of the greatest importance, however, in connection with water supply, not as a direct water-bearer, but as a confining layer to porous sands, from which it prevents water from escaping.

Shale, like clay, is a poor medium for the storage and transmission of water, but may yield it from bedding, joint, or cleavage planes. Its most important use is as a confining mass to prevent the escape of water from porous layers which may be interbedded with it.

The water derived from limestones occurs mainly in open channels dissolved in the rock by the water itself. Probably the water originally followed joint or bedding planes, which were gradually enlarged by solution into the caverns now found. The occurrence of caverns and passages within limestone is very irregular and their location can not be predicted. Wells that are sunk in limestone only a few feet apart may show very different results, for a difference of a foot or two in the position of the boring may mean the missing of a particular channel.

Granites and gneisses are dense and possess small pore spaces, and hence hold very little water. Schists, however, may carry water along the foliation planes, but give it up very slowly, and are not, therefore, important sources of supply. The largest supplies from

schists are obtained along joints. These joints are most common near the surface, diminishing in number and in definiteness as depth increases.

VEGETATION AS A GUIDE.

The flora of the usual thoroughly arid sections of the desert varies but little in character. Tracts for miles in extent are covered by an almost uniform vegetation consisting of but a few species that show only here and there slight variations, due to the local differences in the physical or chemical nature of the soil. The presence of water, however, produces marked changes, hence the character of the vegetation is an excellent indication of the possibility of obtaining water near the surface.

At scattered points in the broader valleys or in the more restricted gulches are numbers of dead sycamores or cottonwoods. Their presence usually indicates the lowering of the water table in that region, and it is not likely that a supply will be found within 20 feet of the surface.

The dry lakes are nearly all absolutely free from vegetation. This lack is probably due to the intermittent flooding of the surface, to the frequently renewed deposits of mud, and to the excess of alkali present.

Although mesquite (*Prosopis juliflora*) grows luxuriantly where water is abundant, its presence is not a good guide to water, for its growth may depend on either the proximity of the ground water or the periodical flooding of a small area. Where its growth is due to ground water it furnishes no suggestion as to the depth to the water. It may lie within a few feet of the surface or it may be 50 feet below. Where its life is sustained, as in restricted gulches, by occasional floods, obviously water will not be found by digging during the drier periods.

Tules, or bullrushes, always indicate water at or very near the surface, and generally water of good quality.

Lowland purslane (*Sesuvium portulacastrum*) is a plant that grows on moist alkaline soils. It indicates water, but usually water of poor quality.

Wild heliotrope (*Heliotropium curassavicum*), sometimes called "Chinese pusley," is one of the rarer plants. It grows only in moist soil, but since it has strong alkali-resisting powers the water near it may be brackish.

Arrowweed (*Pluchea sericea*) is another moisture-loving plant found in the desert. Where it grows to a height of 6 or 8 feet in a dense tangle it is reasonably certain that the ground water lies within 20 feet of the surface and that its quality is at least fair.

Salt grass (*Distichlis spicata*) indicates water very near the surface, but this plant prefers alkaline areas, although not confined to them; hence the water indicated by it may be very brackish.

Creosote (*Larrea mexicana*) and the numerous shrubs (*Sarcobatus*, *Grayia*, etc.) of the greasewood group, which are widely distributed over the deserts, grow in the driest of soils, and although some of them, like creosote, flourish better with a moderate amount of water their presence may generally be taken as an unfavorable indication.

HINTS ON DESERT TRAVELING.

TEAMS, HAY, AND GRAIN.

Where teams are used animals accustomed to the desert should be procured, if possible, for horses or mules that are unused to desert conditions fret on the sandy roads and rapidly weaken from drinking the saline waters. They are also in danger of pneumonia from the cold of the winter nights and the wide extremes of temperature. During winter journeys blankets should be provided to protect the animals at night.

Travel in the desert far from the railroads and from food supplies is, of course, more expensive than in other regions. A party leaving a supply station to go 100 miles or more into an uninhabited part of the desert must take along everything needed, even to the most minute detail. This means that if the trip is to last for two weeks enough hay and grain for each animal and enough provisions to last each man that length of time must be taken. For four horses, drawing a wagon that carries four persons and their bedding, provisions, and tools, another team of four horses must also be taken to haul sufficient hay and grain to feed the eight horses for two weeks. There are but few places in the desert, away from the railroads, where grain or hay of any kind can be procured. As the teams are rarely able to travel faster than a walk, heavy horses that are good walkers should be selected. The tires should be as wide as can be procured. Desirable widths of tires for freight wagons are 6 to 9 inches; for light wagons 3 inches.

A good feed trough may be made as follows: Take two pieces of surfaced 2 by 4 lumber, about 4 feet long. Cross them in the form of an X and fasten them together with a bolt, so that they can be folded for packing in the wagon. Near the top of each arm of the X fasten a heavy hook to which a canvas may be attached. This X should be fastened to the end of the wagon tongue, and a piece of canvas properly shaped should be stretched from it to the front wheels of the wagon to form a broad trough. The tops of the cross-bars should be fastened together with rope to keep them from spread-

ing; the bottoms should rest on the ground. Both hay and grain should be fed from such a trough, which saves waste and provides a more healthful mode of feeding than eating out of the dirt. Nose bags may be carried for feeding grain during the short stops at noon. For packing trips experienced prospectors select burros on account of their endurance of heat and thirst, their foraging abilities, and the slight amount of care they require. They are slow and too light to carry heavy packs, so that on expeditions where speed is essential or heavy freight is to be moved and feed is available, horses or mules are to be preferred.

TOOLS.

Travelers will often find springs choked by débris washed in by rain storms or contaminated by the bodies of desert animals that have fallen in and drowned. It is therefore necessary to provide a pick, shovel, bucket, and rope for cleaning the wells.

CLOTHING, BEDDING, ETC.

At all times except in midsummer—when the desert should be avoided—the traveler must be provided with clothing suitable for both extreme heat and extreme cold. His route over a part of the journey may extend through heated valleys that lie near sea level, or he may have to camp in the mountains, at elevations of 3,000 to 6,000 feet, where the temperature may fall nearly to the freezing point before morning. For protection during the early morning hours he must therefore have warm, heavy blankets and a heavy overcoat or its equivalent. Many cases of pneumonia and “mountain fever” have been caused by extremes of temperature for which no adequate provision had been made. In winter the temperature in this region may reach 85° or 95° during the day and fall to the freezing point before midnight. The traveler should be provided with a canvas sheet that is long enough to lay under his bedding and fold back over it, as well as to cover his head in case of sand storms. Folding cots and air mattresses are luxuries that may be taken if the financial resources of the party are sufficient to provide such supplies and ample means of transportation.

The outer clothing should be of a color that will reflect as much heat as possible—that is, white, gray, or yellow—and the under-clothing should be of wool. The hat should have a wide brim and be thick enough to exclude all rays of the sun. The proper headgear is a broad-brimmed gray felt, or, for summer wear, a big opaque helmet of white or khaki color, the bigger the better. The hair should not be cut very short, as it is a natural means of protection.

Travelers with their own outfits and a minimum means of transportation will find that they must walk much of the time, for teams with

heavy loads can only crawl through the sands at the rate of 2 to 3 miles an hour. Sand and sharp flints will wear out the soles of boots and shoes very rapidly. Hence stout hobnailed footwear should be worn.

PROVISIONS.

In the more important mining camps and at the principal railroad points there are eating houses, where the traveler who follows railway and stage lines may procure food; but in actual desert travel in regions far away from these few local points full provision must be made at the outset for the entire period to be occupied in the journey. The staples of camp supplies, such as flour, sugar, tea, coffee, rice, bacon, beans, breakfast foods, etc., are well known, but means and personal taste will to a great extent dictate the further choice. The monuments of tin cans at the various camping places testify to the popularity of the various foods preserved in tin. The better brands of canned meats, fruits, and vegetables are excellent and will form an important and most refreshing part of the menu of the more elaborately equipped parties. Where long journeys are planned and transportation facilities are limited, canned goods must be eliminated, largely because of their weight, and dried foods substituted. Soups, meats, potatoes, and other vegetables, as well as fruits, may be had in dried form, and a considerable range of choice is possible. Condensed cream is recommended, even where it is necessary to economize in weight, for it not only makes possible a much wider range in cooking, but it counteracts in great measure the irritation produced in the digestive tract by the alkaline desert waters, and is therefore especially desirable.

WATER.

Owing to the intense heat of the desert there is a rapid and abundant growth of minute forms of animal and vegetable life in waters that are not too saline. All water should therefore be boiled before drinking. Filters form a part of the more elaborate outfits. There are now on the market several small, compact filters from which the traveler may select such as he may think desirable. It is not practicable to distill water except for mining camps or for large parties.

It is advisable to drink heartily in the morning and at night and as little as possible during the day. The practice of drinking water in excess of the amount necessary to relieve thirst may easily become a habit and should be avoided. At best it places an unnecessary tax on the system, and, when alkaline waters are used, may easily result in illness that could have been prevented by the exercise of greater foresight and self-control. It has been recommended that raw oatmeal be placed in the canteens, and some travelers even add to this a

small quantity of chocolate and sugar. When the water becomes tepid, additions of this kind make it more palatable to some, and there is less temptation to drink too much. It is well, also, during periods of extreme heat to wrap a wet cloth around the wrists and to put a water-soaked handkerchief in the hat. These are old-fashioned but effective devices. Each person in a party should be supplied with a large canteen, and extra ones should be taken along in the wagons to provide for leaks and accidents. An ample supply of water barrels and kegs should also be carried for use at dry camps and during prospecting trips, the number depending on the amount of stock taken and the route followed.

FUEL.

Fuel is scarce in the desert, especially in the vicinity of the better-known springs, where it has been entirely cleared away. The traveler therefore usually finds it necessary to begin gathering brush and mesquite roots long before he reaches a spring, so as to provide fuel for cooking. Camp fires are luxuries that can be indulged in only among heavy mesquite and cottonwood timber, or off the beaten lines of travel.

GETTING LOST.

One unacquainted with the desert should accustom himself to its clear air and the resulting exaggerated detail, which makes distant objects look near. No walks without water or provisions to what appears to be a near-by hill should be undertaken without definite knowledge of its distance. Landmarks should be studied, so that they will be recognized from any point of view, that they may be known when they are reached again. Before he begins a journey that does not follow a beaten and unmistakable track, the traveler should determine his general direction by compass or map or inquiry, and should adhere to that direction. The inexperienced traveler often gets at once into a panic on losing his way, and wastes his remaining energy in frantic rushes in one direction and another. This tendency to become panic-stricken should be controlled, if possible. Sit down, get out your map and compass—if you are provided with them, as you should be—and study the situation carefully before acting. At least, rest a little and think it over. If it is hot and you are far from camp, get your head into the shade of a bush or rock, and wait till night. Thirst will be less intolerable then and endurance greater. If you have camp companions who are likely to look for you, start a signal fire by night or a smoke by day from some little eminence, and then stay by it until help comes. If you must depend on your own exertions, think carefully over all the possibilities and adopt a plan of action and adhere to it. Remember the proneness of the lost person to exaggerate the distance he has trav-

eled. It is well to count paces and to remember that about 2,000 make a mile. You will thus have a good check on the distance that you go, and at the same time will keep your mind occupied. Keep your direction true by traveling toward or from some selected landmark, or by the sun during the day or a star at night, or by keeping with or against or in some fixed direction in relation to the wind. If you think these things out and have studied the country beforehand, so that you know the relation of a road, or a ranch, or a spring, or a river to a given landmark or to the points of the compass, you should have no difficulty in finding your way again. With some persons, however, the faculty of getting lost amounts to genius. They are able to accomplish it wherever they are. The only suitable advice for them is to keep out of the desert. There are safer places in which to exercise their talent. Still others have a geographic instinct and a power of geographic observation which defies time and place. They can not be lost anywhere. For such these lines are not written.

MAIN ROUTES OF TRAVEL.

STARTING POINTS.

Most of the main routes of travel in the desert are by no means straight, but make long detours, their courses having been determined either by the location of watering places or by the desire to avoid crossing desert ranges. A long way round to a given place on the desert may be not only easier but safer than a more direct line. Nearly all the travel into these regions starts from the Santa Fe, Salt Lake, or Southern Pacific Railroad, and the descriptions that follow are given accordingly. In returning from his destination the traveler has only to retrace his steps.

FRÉMONT'S TRAIL.

Gen. J. C. Frémont, in April, 1844, entered the Mohave Desert at Cameron Salt Lake, about 22 miles northwest of the modern town of Mohave. From that point he followed the east base of the Sierra southward to what is now known as Water station. Thence his course was southeastward past the Desert Buttes, until he reached Mohave River at "Point of Rocks," near what is now known as Cottonwood station, on the Santa Fe. There he turned down the Mohave to the point where the old Spanish trail left it, about 10 miles east of Otis. From that point he followed the old Spanish trail northeastward to Tomaso Springs; thence northward past the east edge of the Avawatz Mountains to Salt Spring and the canyon of the Amargosa, which he followed up to China Ranch Springs, on Willow Creek. From China Ranch Springs he journeyed to Resting

Springs, where his course was altered to the northeast toward Vegas Warm Springs, in Nevada. This route between Cottonwood, Otis, and Resting Springs is still used.

OLD SPANISH TRAIL.

When California belonged to Mexico, caravans made regular trips over a well-defined trail that connected Los Angeles with points in Utah. This trail crossed the mountains north of San Bernardino by the Cajon Pass, and followed Mohave River down to a point east of the Calico Mountains. There the trail forked, one branch leading across the east edge of Alvord Mountain to Bitter Spring and Tomaso Springs and thence northward along the east edge of the Avawatz Mountains to Salt Spring, the other branch continuing down the Mohave to its sink, then crossing Soda Lake and Silver Dry Lake and joining the first branch in the pass between the Avawatz and Shadow mountains. From Salt Spring the trail led northward through the canyon of the Amargosa to Resting Springs, then eastward by way of Stump and Crystal Springs to Las Vegas Warm Springs, where it turned northeastward to Virgin River. This route was used later as the mail route from Los Angeles to Salt Lake City, mail being carried over it once a month for many years.

These roads are still used by travelers from Daggett to Shadow and Silurian mountains or to Soda Lake.

MOHAVE-KEELER ROUTE.

Those who desire to reach points in the western part of Inyo County will find the stage road from Mohave to Keeler the best route. It is an old-established, easily followed road, and watering places and road houses are distributed along it. It follows close to the foot of the Sierra Nevada from Mohave station on the Santa Fe and Southern Pacific railroads, northward to Water station, whence it passes through Redrock Canyon, at the west end of the El Paso Range, and on northward to Freeman, Indian Wells, Little Lake, Haiwee, and Olancho. From Olancho one road skirts the west side of Owens Lake to Lone Pine and Independence, the county seat of Inyo County. From this route, as shown by the map (Pl. I), other roads lead eastward to most of the mining districts.

DEATH VALLEY ROUTES.

There are three main routes by which Death Valley may be reached from the south. One starts from Johannesburg, another from Daggett, and a third from Barnwell.

The Johannesburg route runs by way of Blackwater and Granite Wells. A heavily laden team can leave Johannesburg late in the

morning and reach either of these camping places in the evening. A dry camp should be made between Granite Wells and Leach's Spring, the next watering place, as the distance is 45 miles, and pulling is hard over the last 6 miles on account of deep sand and heavy grades. From Leach's Spring the route leads to Owl Springs, Saratoga Springs, the China ranch, and thence to Resting Springs. At Resting Springs directions should be obtained for going to the head of Furnace Creek, whence the route follows down Furnace Creek to the Borax Works at Coleman, in Death Valley.

The Daggett route is a favorite with many. This road runs from Daggett to Otis, thence east of the Calico Mountains to Coyote Well, and across the dry lake to Langford Well and Garlic Spring. From this spring the road passes to the east of the Granite Mountains and climbs the Avawatz Mountains to Cave Springs. From Cave Springs it leads to Saratoga Springs and thence to Resting Springs.

The Barnwell route was for a number of years traveled by a daily stage running from Barnwell, Cal., to Manse, Nev., but the stage has been abandoned since the construction of the Salt Lake Railroad. This route is still preferred by some travelers, who obtain their supplies at Barnwell or at Ivanpah. From Ivanpah the road extends across the dry lake to the north, thence through the State Line Pass to Mesquite Dry Lake and Sandy; from Sandy northwestward to Stump Spring and Manse; thence to Pahrump and Johnnie and Miller Well No. 2, where it joins the stage road from Las Vegas to Bullfrog.

Outfits may also start from Roach or Jean, Nev., and go westward to Sandy. At Pahrump, on this line, roads branch to the Fairbanks ranch at Ash Meadows, but it is advisable to go by way of Johnnie to Miller Well No. 2, and thence to the Fairbanks ranch, where there are springs. A number of recent changes and improvements in the roads give good routes to the head of Death Valley. Travelers can obtain all information regarding these changes at Pahrump and at the Fairbanks ranch.

BULLFROG ROUTES.

Three main routes lead to the Bullfrog mining district, from Las Vegas, Ivanpah, and Goldfield. Travelers over the Death Valley routes can connect with the Bullfrog roads by driving from Resting Springs to Manse, Pahrump, or the Fairbanks ranch.

A wagon road runs from Las Vegas, Nev., northwestward by way of Tule Spring to Indian Springs, thence westward to Miller Wells Nos. 2 and 1, and northward to Beatty, Rhyolite, and Bullfrog. This route is 130 miles long.

Ivanpah is the terminus of a branch of the Santa Fe Railway which leaves the main line at Goffs (Blake post-office), Cal. From

Ivanpah a stage line runs northward by way of Sandy, Manse, and Pahump to Miller Well No. 2, where it connects with the Las Vegas road. This route is highly regarded, as the water supply is excellent, and hay and grain can be obtained at the four stations mentioned. Bullfrog is about 135 miles in air line northwest from Ivanpah.

A wagon road runs from Goldfield to Bullfrog by way of Cuprite and Bonnie Claire station, which lies on the west side of Sarcobatus Flat. From Bonnie Claire station the stage follows the east foot of the Grapevine Mountains, by way of the Tonopah Well, Seattle Well, and the old town of Bullfrog, entering the new town of Bullfrog from the west. This route is about 80 miles long.

SEARCHLIGHT ROUTE.

The Searchlight mining district is best reached by a branch of the Santa Fe that leaves the main line at Barnwell.

NEEDLES-PARKER ROUTE.

The southeastern portion of the Mohave Desert is best reached by the road running from Needles southward to Parker. Two wells, dug by the county, and known as the "old" and the "new" West wells, furnish water to the traveler. There are no settlements on the route. The completion of the Santa Fe line now under construction from Bengal to Parker will give easier access to this district.

AMBOY-DALE ROUTE.

A stage line connects Amboy, on the Santa Fe Railway with the Dale mining region to the south. Water can be had at the stage station along the line.

MECCA-DALE ROUTE.

An excellent road starts from Mecca, in the Coachella Valley, on the Southern Pacific Railroad, and runs northeastward to Shaver well, thence along the west flank of Eagle Mountains and the east side of Pinto Mountain to Dale. This road is well supplied with good water, and is the main route into this region from the south.

VICTORVILLE ROUTES.

Victorville station, on the Santa Fe Railway, is the starting place for points in the southern portion of the Mohave Desert east of the Santa Fe. A county road crosses Mohave River here by a good bridge, and branches of this road run along the east side of the river to the various mining camps. The main county road runs eastward by way of Dead Man's Point, at the south end of Granite Mountain, to Box S ranch. At this ranch the road forks, a northern branch lead-

ing eastward by way of Old Woman Springs, Mean's Well, and Surprise Spring to Twenty-nine Palms Springs and Dale. The southern road goes by way of Box S Springs, Cushenbury Springs, and the Rose Mine to Twenty-nine Palms Springs. This road crosses the northern edge of the San Bernardino Range, rises to high altitudes, and has heavy grades. The northern route is the better.

BANNING-DALE ROUTE.

From Banning a wagon road runs by way of Warren's Ranch, Warren's Well, Coyote Holes, and Twenty-nine Palms Springs to Dale.

IRRIGATING AND ARTESIAN WATERS.

IRRIGATED AREAS.

The arid region shown on Plate I is bounded on the east, west, and south, respectively, by Colorado River, the Sierra Nevada, and the Sierra Madre. The only places in this wide area where irrigation is generally practiced are found along the east base of the Sierra Nevada in Inyo County; in the Elizabeth Lake, Palmdale, and Little Rock districts north of the Sierra Madre in Los Angeles County; in a few small tracts along Mohave River in San Bernardino County; in the Imperial district in Imperial County; the Indio section in Riverside County, and at a few points along Colorado River. In the desert proper the patches reclaimed by irrigation vary in size from 4 or 5 acres to 160 acres, and are isolated and exceptional, serving only to emphasize the barrenness of the rest of the region. These oases are all watered from springs and will be mentioned in the detailed descriptions.

ARTESIAN WATERS.

Certain areas give evidence of having a supply of artesian water as yet undeveloped or but partly developed, but their exact limits and the amount of water available in them can be ascertained only by special study. The writer desires to call attention to the fact that they exist and that some of them are worthy of detailed investigation.

Artesian zones border some of the larger playas or dry lakes which have a relatively abundant water supply. Near the southern and western limits of the Mohave Desert there are several such basins whose waters are supplied by the run-off from the Sierra Madre and Sierra Nevada. An important basin of this type exists also in the northwest arm of the Colorado Desert, about Indio, where several thousand acres of land are under irrigation by the use of artesian waters.

In addition to water in sufficient quantity to give the necessary head, certain mechanical conditions, such as a proper alternation of pervious and impervious strata, are necessary to establish and maintain artesian conditions. Furthermore, such basins in the desert are usually readily exhausted, because the amount of water available to replenish that drawn out for irrigation or other uses is small. In planning municipalities, large mining camps, or extensive irrigation from such waters, care must be taken that their quantity is not overestimated.

Artesian waters have been obtained near Haiwee, in Inyo County, between the Sierra and the Coso mountains; at the head of the Salt Wells Valley between the El Paso Range and the Sierra; and west of Kane Dry Lake in Kern County. Another belt in which artesian waters have been developed lies along the north edge of the Sierra Madre in Los Angeles County, in the vicinity of Lancaster. Other artesian belts lie east of the latter zone along the north front of the San Bernardino Range, in the neighborhood of Victorville and farther east in what is known locally as the Lucerne Valley district. The principal wells drilled in this valley are mentioned under the heading "Box S ranch."

Artesian waters have been tapped in the northeast corner of Riverside County, in T. 2 S., R. 19 E., San Bernardino meridian. They have been found also on the northeast edge of the basin, of which Rodriguez Dry Lake is the sink, at the Flowing Wells.

DESCRIPTIONS OF SPRINGS.^a

SYMBOLS USED.

Springs, wells, flowing wells, and pumping plants are represented on the map by appropriate symbols, and those described in the text are given numbers; others, whose locations are known but for which no descriptions are available, are indicated by symbols only.

In the arrangement of the descriptive matter the plan adopted is to divide the map into rectangles, each covering an area of approximately four townships. These rectangles are identified by letters and numbers along the margins of the map. The numbers and the corresponding descriptions in the text begin at the northwest corner of the map and follow the first row of rectangles eastward to the Nevada line. They then begin in the next row of rectangles to the south and follow it eastward. When all of the descriptions available for California have been given in this order, the same plan is adopted for that part of Nevada described, but the California and Nevada numbering is continuous. Locations can not be given by land lines, because there are many unsurveyed areas in the desert, and even

^aArranged by map numbers. References to positions on the map, in parentheses, follow the headings.

where surveys have been made they are old, much of the work having been done between 1852 and 1860, and corners are usually missing. Both on this account and because of the very general way in which many of the springs have been located it is not possible to give the section within which they are found.

CALIFORNIA.

1. *Oasis, Mono County (A-2).*—Oasis is a settlement near the California-Nevada line west of the Palmetto Range. It is about 30 miles northeast of Alvord station, on the Southern Pacific Railroad, and about 15 miles northeast of Deep Springs (No. 2). Oasis serves as a general outfitting point for prospectors in the Palmetto Range. It is well supplied with water from both springs and wells.

2. *Deep Springs, Inyo County (A-2).*—At the south end of Deep Springs Valley there are large flowing springs that have been known since the earliest settlement of the north end of Inyo County, and that have given a name to the settlement and to the valley. They are 13 miles east of Poleta station and about 18 miles northeast of Alvord station, on the Southern Pacific Railroad. They furnish sufficient water to irrigate about 600 acres. The settlement is the principal stopping place between Alvord and Oasis.

3. *Sand Springs, Inyo County (B-3).*—Sand Springs are about 19 miles west of south, in an air line, from Lida, Nev., on the west side of the north end of Grapevine Mountains. They are in Termination Valley near its north end, about 16 miles northwest from Staininger's ranch (No. 5). The water is good, and the site of the springs is marked by the debris left by many campers.

4. *Grapevine Springs, Inyo County (B-3).*—This is a group of springs on the bench above the floor of Death Valley, about 3 miles by trail due west of Staininger's ranch. There is plenty of water.

5. *Staininger's ranch, or Grapevine ranch, Inyo County (B-4).*—This ranch is in Grapevine Canyon, which drains into Death Valley, about 22 miles southwest from Bonnie Claire station, on the Las Vegas and Tonopah Railroad. It is about 11½ miles, air line, northwest of Grapevine Peak. There is an unlimited supply of good water.

6. *Barrel Springs, Inyo County (C-1).*—There are springs of excellent water in Mazourka Canyon in the Inyo Mountains, about 10 miles northeast of Independence and 6 miles north of Citrus station, on the Southern Pacific Railroad.

7. *Cold Springs, Inyo County (C-3).*—There are two groups of springs near together in the northeast portion of T. 13 S., R. 39 E., about 10 miles northeast of the Saline Valley borax works (No. 13). The springs of one group yield hot water, those of the other cold water. The hot springs lie farther south than the cold. The water

from the springs of both groups is of good quality, and there is a sufficient quantity, if developed and conserved, to irrigate several acres.

8. *Rest Spring and Burro Spring, Inyo County (C-3).*—Rest Spring is in a shallow gulch at the head of a canyon draining southward and westward into Butte Valley. It is one-half mile west of the summit of the Panamint Range and 15 miles north of Goldbelt Spring (No. 15), to which there is a plain trail. It is $6\frac{1}{2}$ miles south of Tin Mountain, the northernmost peak of the range. The flow is about 3 barrels of water daily. A trail running due north leads to Burro Spring, $1\frac{1}{2}$ miles distant. This spring is in a shallow gulch at the head of a canyon draining southward and eastward into Death Valley, one-fourth of a mile east of the divide. This spring also yields about 3 barrels of good water per day.

9. *Mesquite Spring, Inyo County (C-4).*—This spring is in the east bank of the wash in Death Valley, one-half mile from the bottom. It is 6 miles southwest of Staininger's ranch, 19 miles southeast of Sand Springs, and 11 miles northwest of the locality known as Lost Wagons. There are other springs in the desert portion of California and Nevada that are also known as "Mesquite" springs.

10. *Indian Springs, Inyo County (C-4).*—Like "Mesquite," the name "Indian" is applied to several desert springs. Those here referred to are near the northeast end of the great Panamint Range and near the south end and west side of Termination Valley on an old and little-used trail that runs southward from Lida, Nev., by way of Sand Springs to the north end of Death Valley. They are marked by remains of Indian tepees. There are said to be other springs in this vicinity, but their location is unknown except to local prospectors.

11. *Tule Spring, Inyo County (C-5).*—This spring is about 3 miles south of west, air line, from Willow Spring (No. 12) and 12 miles southwest of Bullfrog, Nev. It is on the north side of the east branch of a canyon at the foot of a cliff, $1\frac{1}{4}$ miles southeast of the high, sharp, rocky Thimble Peak. It is about 500 yards east of the trail from Bullfrog to Surveyors' Well (No. 18) by way of Willow Spring (No. 12). There is a very small quantity of excellent water. There is another Tule Spring to the southeast, near Tecopa.

12. *Willow Spring, Inyo County (C-5).*—This spring is on the east slope of the Grapevine Range, 9 miles southwest of Bullfrog, Nev., and 3 miles north of the Boundary Canyon road at the pass. The flow is 10 barrels of good water daily. There are at least 8 watering places in the desert region with which this paper deals that are known as Willow Spring or Willow Springs; so this is by no means a determinate name.

13. *Saline Valley Well, Inyo County* (D-2).—Twenty years ago Conn & Trudo manufactured borax on an old dry lake in Saline Valley, and dug a well near the works that furnished a good supply of water of fair quality. The well is still used by prospectors on their way to the copper regions on the eastern side of Saline Valley.

14. *Bird Spring, Inyo County* (D-3).—There is a spring of pure water on the trail from Keeler to North Death Valley near the mouth of a canyon on the east side of the Pinto Mountains.

15. *Goldbelt Spring, Inyo County* (D-4).—Goldbelt Spring is near the head of a western branch of Cottonwood Canyon, known as Marble Canyon. It is 8 miles by trail northwest of the head of Cottonwood Creek, 4 miles northeast of the crest of the Panamint Range, and nearly 25 miles southwest of Surveyor's Well (No. 18) in Death Valley. The spring, which is surrounded by bushes, is on the south bank of the canyon, about 100 feet above the bottom of the wash. It flows about 20 barrels per day.

Two miles east of Goldbelt Spring, and down the canyon from it, is a small spring in a clay bank on the south side of the wash. It yields perhaps 3 barrels per day.

16. *Well, Inyo County* (D-4).—This well is 7 miles southwest of Surveyor's Well, on the southwest edge of Mesquite Flat, south of the trail from Surveyor's Well to Cottonwood Canyon. The trail is often buried in sand and obscure, and the water is not always easy to find.

17. *Ring or Ruiz Well, Inyo County* (D-4).—This well is 2 miles southwest of Surveyor's Well, in the Mesquite Flat that occupies this portion of Death Valley. The trail to it may be buried in sand, and the water difficult to find. The well is 4 feet deep, and the water good, although slightly brackish.

18. *Surveyor's Well, Inyo County* (D-4).—This well is at the northeast corner of Mesquite Flat, on the main road from Staininger's ranch to Furnace Creek. It is 19 miles southeast of Mesquite Spring, 8 miles southeast of the locality known as Lost Wagons, and 20 miles southwest of Bullfrog in an air line. The position of the well is clearly marked by camp débris. The well is 5 feet deep and the water obtained from it is good, although slightly brackish. A trail leads from it southwestward to Marble Canyon.

19. *Triangle Spring, Inyo County* (D-4).—This spring is 3 miles southeast of Surveyor's Well, on the road from Staininger's ranch to Coleman (Furnace Creek ranch), 5 miles northwest of Stovepipe Wells (No. 20), and one-half mile east of Sandy Flat. It is in a clay bank, marked by a growth of mesquite. There is a small quantity of good water.

20. *Stovepipe Wells, Inyo County (D-4).*—These wells are near the intersection of the Bullfrog-Ballarât and Staininger-Furnace Creek roads, 25 miles southwest of Bullfrog. They are on the eastern edge and near the south end of Mesquite Flat, 6 miles southwest of Death Valley Buttes. The main road southeastward from them leads to Furnace Creek; the one to the northwest to Grapevine Canyon; the one to the northeast to Rhyolite, Nev., by way of Boundary Canyon; and the one to the southwest to Keeler, by way of Emigrant Canyon. There are two wells about 5 feet deep that yield an abundance of good water.

21. *Daylight Spring, Inyo County (D-5).*—This spring is just north of the pass in the Grapevine Range, on the wagon road from Bullfrog, Nev., to Furnace Creek and Ballarât, Cal. It is about 10 miles southwest of Bullfrog. The spring is 300 yards west of the road, on the side of the hill. The flow is about 8 barrels of good water per day.

22. *Keane Spring, Inyo County (D-5).*—This spring is on the west slope of the Grapevine Range, about 3 miles a little east of south of Daylight Spring and 4 miles northwest of the Chloride Cliff mine. It is accessible by wagon from Boundary Canyon by the road turning east up the first large wash south of Daylight Spring. The flow is 30 barrels of good water per day.

23. *Hole in the Rock Spring, Inyo County (D-5).*—This is a seep in a hole which may contain 6 or 8 gallons of water. It is about 5 miles southwest of Daylight Spring, one-half mile north of the wagon road in Boundary Canyon, and 3 miles northeast of Death Valley Buttes.

24. *Salt Creek Wells, Inyo County (D-5).*—These are two small wells in sandy earth at the foot of a low hill near the east edge of Salt Flat. They are about 5 miles southeast of Stovepipe Wells on the road to Furnace Creek ranch. The road to Ballarât turns west and crosses Salt Creek here. The water in the creek is very salty; that in the wells is brackish, but usable.

25. *Poison Spring, Inyo County (D-5).*—This spring is 11 miles east of north of the Furnace Creek ranch (Coleman) in the bottom of a very narrow limestone canyon, the deepest in the vicinity. It is 250 yards northeast of the trail from Furnace Creek ranch to Bullfrog via Indian Pass and Amargosa Desert, and is difficult to find. There is a small seep of water, which may be used in limited quantities.

26. *Springs (no name), Inyo County (E-2).*—There are a number of springs near the southeast edge of Owens Lake, which have long been known to the stockmen of that region. The springs rise from the alluvium that surrounds the lake, and the water is brackish. It is too full of mineral matter to be palatable, but serves for stock, and is a watering place on the Mohave-Keeler stage road.

27. *Cottonwood Creek, Inyo County (E-4).*—Cottonwood Creek, a stream of fine, clear water, rises in a large spring about 10 miles above

the mouth of Cottonwood Canyon and flows about 2 miles before disappearing. The canyon opens into Death Valley 11 miles southwest of Surveyor's Well and 11 miles almost due west of Stovepipe Wells. The main trail from Death Valley to Keeler via Bird Springs and Cerro Gordo follows it.

There are a number of small springs in the upper branches of Cottonwood Canyon. One is $3\frac{1}{2}$ miles west of the head of Cottonwood Creek, in a side canyon just south of the main western branch. Another is 5 miles above the head of Cottonwood Creek, in the main canyon, on the main trail from Death Valley to Keeler. Still another is $1\frac{1}{4}$ miles northwest of the last, across the divide, 300 yards from the trail, in a small flat.

28. *Emigrant Springs, Inyo County (E-4).*—Emigrant Springs, which have been used since 1852, are in the northern portion of the Panamint Mountains, nearly opposite the north end of the sink of Death Valley, and about 20 miles west of the mouth of Furnace Creek. They are in Emigrant Canyon, the main pass through the Panamint Range, on the wagon road from Ballarat to Death Valley, Chloride, and Bullfrog. This road also passes Wild Rose Spring (No. 42), which is about 14 miles south of Emigrant Springs. Emigrant Springs receive their name from the fact that they were used by the early emigrants from Salt Lake City, who entered Panamint Valley by this route. They are in a canyon draining northward into Death Valley, at the north end of Tucki or Sheep Mountain, 19 miles from Surveyor's Well, in a wash at the foot of a limestone wall 20 feet high, 25 yards west of the wagon road. The supply is about 50 barrels of good-water per day.

29. *Spring (no name), Inyo County (E-4).*—This is a small spring in the mountains about 3 miles east of Wild Rose Spring. It is in a canyon off the main road that passes Wild Rose Spring, about 2 miles from the road. There are a number of other springs, known to prospectors, on the west side of the Panamint Range, but they are away from traveled routes.

31. *Salt Well, Inyo County (E-5).*—This well is on the road from Furnace Creek ranch to Stovepipe Wells. It is 10 miles northwest of the ranch and 4 miles southeast of Stovepipe Wells. The water, which is too salt for human beings, but may be used by stock, is obtained from a hole in a clay bank 100 yards west of the main road. Well No. 61 is another "salt well," about 10 miles northeast of Searles, on the road between Johannesburg and Ballarat. Salt Spring (No. 75) is in the extreme southeastern end of Death Valley.

32. *Fountain Springs, Inyo County (E-5).*—There are small springs at the east edge of the butte that lies just east of the sink of Death Valley, about 6 miles north of Coleman. They are used by prospectors and miners in the Amargosa Range.

33. *Coleman Springs, Inyo County (E-5).*—Coleman was originally known as the Greenland ranch. It is now better known as the borax camp of the Pacific Coast Borax Company, and is the point from which the much advertised "20-mule teams" once hauled borax across the desert to Mohave. The springs are near the northeast end of the sink of Death Valley, at the mouth of Furnace Creek, about 50 miles by wagon road via Boundary Canyon south of Bullfrog. The water, which is abundant, is used to irrigate over 100 acres of alfalfa. It contains some saline matter, but is not unpleasant to taste and is used without injurious effects during the winter season, the only time when work is carried on in Death Valley.

The springs are about 200 feet above sea level, and are reached by two roads from Fairbanks Ranch, Nev., one running nearly due west across the Funeral Mountains to Furnace Creek and down its canyon; the other passing south of the Funeral Mountains, by way of Franklin Dry Lake, to the head of Furnace Creek Canyon.

The old route from Coleman to Mohave crosses the sink of Death Valley to Bennet's Wells (No. 44) by a road formed by crushing the hummocks of salt that cover the valley floor. From Bennet's Wells this road follows the west side of the valley to the south end of the sink, then turns southwest through Windy Gap to Lone Willow Spring (No. 65) and passes on by way of Granite Wells (No. 96) and across Willard Dry Lake to Mohave. This road is in many respects the best through Death Valley. The chief objection to it is the long drive of over 50 miles to Bennet's Wells from Lone Willow Spring without water.

Travelers are cautioned not to attempt to reach Coleman from Saratoga Springs (No. 74) by traveling down the valley of the Amargosa, unless they have a guide who knows just where to find the Confidence Springs (No. 49) in the Amargosa Range near the Narrows. These springs are 7 miles north of the ruins of the old Confidence Mill. Two trails run northward from this mill; the one that branches to the east goes to the old mines and the one to the northwest goes to the springs. As this is the only water for nearly 70 miles on a poor road the trip is a dangerous one, to be avoided under all ordinary conditions. (See "Death Valley routes.")

34. *Cow Creek, Inyo County (E-5).*—This stream, formed by the flow from constant springs, is in the canyon on the west slope of the Funeral Range, 8 miles northeast of Furnace Creek ranch. It is accessible from Death Valley and by trail from the Amargosa Desert by way of Lee's camp. There is an abundance of good water. There are springs known as Cow Springs (No. 47) on the western edge of Owens Valley.

35. *Franklin Well, Inyo County (E-6).*—A well was dug in 1852 by a Mr. Franklin near the north edge of Franklin Dry Lake, at the

foot of the south end of the Funeral Mountains, to supply water for surveying parties at work on the boundary line between California and Nevada. The old road from Furnace Creek to Fairbanks Ranch (Ash Meadows) passed this well, which was in existence in 1901, but other wells have been dug recently on the east side of Franklin Lake south of Fairbanks Ranch, so that travelers now rarely have occasion to hunt for the old well. It was originally about 20 feet deep, and its position is marked by the débris of campers.

36. *Rose Springs, Inyo County* (F-2).—These are well-known springs between Haiwee and Owens Lake and about 8 miles west of Coso Peak. The water is of excellent quality.

37. *Arab Spring, Inyo County* (F-2).—Arab Spring is on the east side of the Coso Mountains, about 9 miles southeast of Owens Lake in an air line. It is about 6 miles south of Omes, on the road to Coso, and about 11 miles due west of Darwin. The spring has long been used and is well known and easily found.

38. *Crystal Springs, Inyo County* (F-3).—Springs of excellent water are located about 6 miles north of Coso and 8 miles southwest of Darwin, on the road between the two settlements. The road from Keeler to Junction by way of Omes and Arab Spring also passes them. They have been known and used for more than forty years. There are other Crystal Springs (No. 316) eastward, in Nevada.

39. *Coso, Inyo County* (F-3).—Coso is a mining and agricultural settlement on the southeast side of the Coso Mountains. It is reached from Keeler by way of Omes, Arab Spring, and Crystal Springs, or by way of Omes, Darwin, and Crystal Springs. It is well supplied with water, and supplies for travelers can be obtained there. The water comes from granite and is of characteristic purity.

40. *Willow Springs, Inyo County* (F-3).—These springs are away from the main roads and trails, in Darwin Canyon, about 4 miles northeast of Darwin post-office, at an elevation of 3,600 feet. Their exact location can best be ascertained by inquiring at the post-office. The water is said to be excellent. There are other springs of the same name (No. 87) about 10 miles northwest of Randsburg.

41. *Spring (no name), Inyo County* (F-3).—This spring is in the pass at the north end of the Argus Mountains, on the road from Darwin to Junction. It has long been a camping place and is therefore clearly marked. The water, like that at Coso, comes from granite and is of excellent quality.

42. *Wild Rose Spring, Inyo County* (F-4).—This is a well-known spring and one of the principal stopping places on the road from Ballarat to the Panamint Valley and the north end of Death Valley. It is situated in Wild Rose Canyon, on the west side of the Panamint Range, about 20 miles north of Ballarat. There is also a road to it from Owens Lake, by way of Darwin. The water is excellent and

abundant. The spring has been a camping place for years and is easily found.

43. *Tule Springs, Inyo County (F-5).*—Tule Springs are on the western edge of the sink of Death Valley, about 5 miles north of Bennet's Wells. They are by the side of the only road that traverses the west side of the valley and are marked by small clumps of tules. The yield is small and the springs are usually partially choked with mud. The water is brackish and not so good as that at Bennet's Wells.

44. *Bennet's Wells, Inyo County (F-5).*—These watering places are on the west side of the sink of Death Valley, about halfway between its south end and the mouth of Furnace Creek, at 260 feet below sea level. They lie west of the lowest point in the sink, which is about 276 feet below sea level. A wagon road from the south end of the valley passes the wells, whose position is marked by a growth of tules, by many evidences of former camps, and by the ruins of the works of the Eagle Borax Company, which at one time operated there. The "wells," so called, are springs that were dug out and protected by barrels many years ago, and were used, until about twelve years ago, by the mule teams that hauled borax from the north end of Death Valley.

The Panamint Range is precipitous along its eastern edge, and there is but little room for a road between the foot of the range and the edge of the sink. The whole surface of the sink is covered with heavy saline deposits, which can be crossed at only a few places. The water from the old wells contains much mineral matter, mainly salt and sulphate of soda.

As there are few travelers over this route now, the springs are apt to be choked with drifting sand and must be cleaned out before a supply of water can be obtained. When the springs are cleaned the water can be used by men as well as by animals, but is not very palatable.

45. *Springs, Inyo County (F-6).*—There are a number of springs on the west side of the Black Mountains, near the summit, that give a small amount of water for several months of the year, but are generally dry during the summer. They are called springs by the prospectors, but are not to be depended on for a steady water supply.

46. *Greenwater, Inyo County (F-6).*—This is the business center of the Greenwater district. It is reached by stage or by automobile from Zabriskie, on the Tonopah and Tidewater Railroad, or from Amargosa, on the Las Vegas and Tonopah Railroad. Water is hauled to the district at present, but pipe lines are being put in.

47. *Cow Springs, Inyo County (G-2).*—These are small springs about 5 miles west of Little Lake, and are used by prospectors in that region. They are not on any main road.

48. *Spring (no name), Inyo County (G-3).*—This spring is in a pass at the north end of the Argus Mountains, on the road from Argus by way of Junction to Ballarat. As it has been used for years, it is plainly marked by the débris of camps. A road turns northward here toward Darwin and to Modoc. The water is good.

49. *Confidence Springs, Inyo County (G-6).*—These springs are about 7 miles north of the ruins of the old Confidence gold mill in the Amargosa Range, near what is called the Narrows, in South Death Valley. The old mill is about 20 miles northwest of Saratoga Springs. It was operated by the Mormons more than twenty-five years ago on silver ores taken from a mine in the mountains 7 miles north of the mill. Its situation is marked by the ruins of adobe houses that can be seen for 5 or 6 miles. These houses are on the north side of the valley, by the old wagon road. In 1903 there remained also some old feeding troughs and the wreck of the stables. There is a shaft near the ruins of the stables that is about 100 feet deep, but it contains only a heavy brine.

A trail leads from the mill northward into the mountains for 3 miles and then branches, one branch leading to the right, or east, across to the mines, where there is no water, the other to the left, or west, to the springs. This trail is obscure and the springs are small and not easily found. The water was at one time piped to the old mill and remnants of this pipe aid in finding the trail.

Between the springs and Bennet's Wells, a distance of more than 30 miles to the northwest, there are no other springs known near the road, so that the long trip from Saratoga Springs into the sink of Death Valley by this route is dangerous. (See Coleman Springs, No. 33.)

50. *Hot Springs, Inyo County (G-7).*—There are two hot springs on the eastern edge of Resting Springs Dry Lake, about 3 miles southeast of Zabriskie. These springs yield about 200 gallons per minute of water which contains, according to qualitative determinations, sulphates of soda and magnesia, some borax, and some niter. In the fall of 1908 there was an old tent at the springs, which are occasionally used for bathing purposes. The temperature of the water is about 107° F. They are about one-half mile northeast of the Tonopah and Tidewater Railroad, and a ditch and pipe leads part of the water to a watering tank beside the track.

51. *Resting Springs, Inyo County (G-7).*—Resting Springs, elevation 1,750 feet, are a well-known stopping place for all who travel in the northern part of the desert. Philander Lee has made his home here for thirty years, and his ranch of 200 acres, with shade trees, fruits, garden, and alfalfa fields, is a veritable oasis. These springs, the China ranch, and Coleman are the only places in the Death Valley region where hay can be procured. The ranch and springs are at

the south end of the Resting Springs Mountains. The waters well up from sandstone and are clear and wholesome. The Lee ranch is about 8 miles east of Zabriskie, a station on the Tonopah and Tidewater Railroad.

There are wagon roads to these springs from the east by way of Ivanpah, on the Santa Fe Railway, and thence northward to Sandy; or from Jean, Nev., on the Salt Lake road, westward to Sandy. At Sandy travelers can procure hay, grain, and other supplies. From Sandy the best route is northward by way of Manse where directions may be obtained for going to Resting Springs, about 35 miles to the southwest. There is also a road from Stump Spring directly west to Resting Springs, but it is rocky, and because of the drifting sands is apt to be dim and not easily followed.

There is an old trail from Sandy to Horsethief Spring (No. 79), thence along the north edge of the Kingston Mountains to Tecopa, and on to these springs, but it is unwise to attempt to follow this road without an experienced guide.

From Resting Springs a road runs westward across Resting Springs Dry Lake to the buildings of the old Amargosa Borax Company. There one road turns southward by way of the Ibex mine to Saratoga Springs, and another turns northward to the head of Furnace Creek. Formerly no water was procurable along the latter route between Resting Springs and Coleman, a distance of 50 miles, but conditions have been altered since the Greenwater mining camp was established.

The old San Bernardino and Salt Lake emigrant road passes these springs and goes through Emigrant Pass, just north of the ranch, and thence eastward by way of Stump Spring to Las Vegas. In the days of the old "Spanish trail" these springs were known as the Archilette. J. C. Frémont camped by them April 29, 1844, and named them "Agua de Hernández," for the survivor of a party of emigrants who were murdered there. Frémont rescued Hernández and buried his companions. He described the place as "a grassy spot, with springs and bushes, which make a camping place."

52. *China ranch, Inyo County* (G-7).—China ranch, elevation 1,357 feet, also known as Morrison ranch and Willow Creek ranch, is on the main road from Daggett to Resting Springs. On leaving Cave Springs (No. 73) and passing down the north side of the Avawatz Mountains into the bottom of Death Valley, the road branches, one fork turning to the northwest, to Saratoga Springs (No. 74), and the other continuing a little east of north, across the flat, and to China ranch. This road is frequently obscure, as it is not often traveled and the sand drifts over it. Nearly all travelers go to Saratoga Springs and stay there over night, as the road across Death Valley is very sandy. It is about 30 miles to China ranch from Cave Springs direct, and

about 20 miles by road from Saratoga Springs. To find the ranch from Saratoga Springs one may either travel eastward past the foot of the Black Mountains, and then northeastward through a pass in the lower ridge ahead, passing along the south edge of the sand dunes, or may take the road around the southern end of this lower ridge.

Travel is difficult for $1\frac{1}{2}$ miles through the sand dunes and across the pass, but the route is shorter than that to the south around the ridge. From the east side of the divide the road bears sharply northeastward to the mouth of Amargosa Canyon, which can be seen from a distance. When the mouth of the canyon is reached water can be had from the river. Stock will drink it, but it is strongly alkaline. The road then runs up the canyon for about 9 miles, passing under two trestle bridges of the Tonopah and Tidewater Railroad, 2 or 3 miles north of Sperry station, then crosses the track and turns eastward to the ranch, about 5 miles above Sperry. The road thence keeps a straight course northward up Willow Creek, from which the ranch derives its water supply. The springs that furnish this water rise in Tertiary rocks, which outcrop around the ranch to a height of 500 to 600 feet.

Good hay can be obtained here, the first to be had after leaving Daggett, 110 miles south. Willow Creek furnishes sufficient water to irrigate about 100 acres of land. This ranch is one of the real oases of the desert, and travelers appreciate the cool water, the supply of alfalfa, and the shade of the fig trees.

Resting Springs are about 6 miles northeast of this ranch and Tecopa is about 7 miles east. The old emigrant road from Salt Lake passed here on its way south by way of Soda Lake and Salt Spring (No. 75) to Cajon Pass.

J. C. Frémont passed this spot April 29, 1844, on his way from Tomaso Springs (No. 103) to Resting Springs. He says of it: "The ravine [Amargosa Canyon] opened into a valley [Willow Creek], where there were springs of excellent water."

53. *Tule Spring, Inyo County* (G-7).—This spring is about 3 miles northeast of Tecopa along the roadside on the north slope of the rise near Dry Lake, between Tecopa and Manse. It has been roofed over to protect the water from cattle. The supply is not large, but the water is of fair quality. From 1 to 2 barrels at a time may be dipped from the springs.

54. *Tecopa Well, Inyo County* (G-7).—Tecopa is an old lead-mining camp at the head of Willow Creek, on the north side of the Kingston Mountains. When silver mining was active this was a large camp, with a lead smelter and many adobe houses. In the fall of 1908 mining was resumed and the locality is again a center of activity. The place is supplied with a well which stands by the

roadside about 100 yards east of the old smelter. The water is excellent, and is usually 7 or 8 feet deep.

Tecopa is about 7 miles east of China ranch, on the main road from that place to Manse, Nev. It is easily found by following the road directly up Willow Creek from China ranch to the smelter. There is also a wagon road from Tecopa to Resting Springs, which lie about 5 miles north. It is 7 miles southeast of Tecopa station, on the Tonopah and Tidewater Railroad.

55. *Grapevine Springs, Kern County (H-2).*—These springs are 4 miles north of Indian Wells station, on the road to Owens Lake. They lie near the edge of the road at the foot of the Sierra Nevada. A short distance above the springs in Grapevine Canyon running water is always to be found. The wild grapes which grow in the canyon have given it its name. The water is of excellent quality and the supply is ample for camping parties. There are other springs known by the same name near the Staininger ranch, in the Grapevine Mountains.

56. *Freeman post-office, Kern County (H-2).*—Freeman post-office, elevation about 3,370 feet, is a well-known camping place at the point where the old emigrant road from Bakersfield, by way of Walkers Pass, reaches the desert. Here there are a number of buildings, including a post-office and a small supply store. Meals and accommodations for the night may also be obtained here. There is a fair supply of water. Roads lead from this point in several directions. One passes southward by way of Redrock Canyon to Mohave, and one by way of Haggin Well (No. 86) and Willow Springs (No. 87) to Randsburg, while another runs eastward to Searles.

57. *China Well, San Bernardino County (H-3).*—An old well was dug at the Chinese camp north of China Dry Lake when the borax deposits were worked in 1890–91. There is a road leading to it by way of Lander Well (No. 58) from Gardners station (Searles post-office). At it the roads branch, one branch leading westward to Indian Wells and Little Lake, and the other northward to Argus. The well is not kept cleaned and the water is of only fair quality.

58. *Lander Well, Kern County (H-3).*—This is an old well on the road from Randsburg by way of Searles post-office (Gardners station) to China Lake, thence northward to Argus and other points in Inyo County. The well is about 6 miles northwest of Searles, near a vacant house. The water is slightly alkaline, but of fair quality. The next water toward the north is found at China Well, 14 miles away.

59. *Searles Springs, Kern County (H-3).*—These springs are about 5 miles southwest of Searles post-office. They supply that stage station with water.

60. *Searles post-office, San Bernardino County (H-3).*—Searles post-office, locally known as Gardners station, is a well-known stage station 18 miles north of Johannesburg, on the road to Ballarat. Water is piped to it from springs about 5 miles southwest, and is sold to travelers. The water is of excellent quality, but the supply is meager. In addition to the post-office and stage station there are, at this point, a store, a telephone station, and a corral.

61. *Salt Well, San Bernardino County (H-3).*—This is a well sunk by the stage company on the road from Johannesburg to Ballarat at an elevation of 2,200 feet. On reaching the divide north of Searles post-office the traveler will see, at the foot of the grade, a dry lake covered with a white crust of borax. The well is about half a mile south of this lake, on the west side of the road. Its position is indicated by a new adobe building and by the ruins of an old adobe building and a stamp mill. The water is brackish but drinkable, and the well is supplied with a good iron pump. In Death Valley there is another "salt well," No. 31, in which the water is stronger than at this one near Searles.

62. *Quail Springs, San Bernardino County (H-3).*—These small springs are in the broken country about 8 miles east of Searles post-office. They are distant from all roads and trails and are used only by prospectors who are thoroughly familiar with the region. Other unimportant springs of the same name (No. 67) lie in the Quail Mountains, about 35 miles to the east; while at the north base of San Bernardino Mountains there is a third group of the same name (No. 210).

63. *Borax works at Searles Lake, San Bernardino County (H-4).*—Water can be obtained at the stage station at the old borax works on Searles Borax Lake, on the stage road from Randsburg to Ballarat. Water is piped to the station from springs several miles away, in the Argus Range.

64. *Slate Range gold mine, San Bernardino County (H-4).*—This mine is on the west side of the Slate Mountains and on the east side of Searles Borax Lake. Where the stage road from Johannesburg to Ballarat reaches the southwest corner of Searles Lake a well-traveled road turns eastward across the lake. This road is cut deep into the borax crusts and leads directly to the mine, whose buildings can be seen from a distance of several miles. The mining company has a number of wells that supply the camp and mill, and the miners at the camp can direct travelers to other springs in the mountains farther north.

Near the east side of the dry lake a dim road turns southward up a canyon at the foot of the range. It branches southward to Granite Wells (No. 96) and eastward to Leach's Spring (No. 69).

65. *Lone Willow Spring, San Bernardino County (H-4).*—This spring has long been known to desert travelers, as it is the first watering place north of Granite Wells (No. 96) on the road to Panamint Valley. It is about 25 miles north and a little east of Granite Wells. The spring is in a canyon in the pass between the Slate Range and Brown Mountain. It was at one time one of the stations for the "20-mule teams" hauling borax from Death Valley to Mohave, and the site of the station is indicated by old troughs and by the pipe that carries the water, whose quality is excellent, from the springs to the road. The spring was named from a lone willow that once stood near it. A short distance north of it the road branches, the eastern branch leading to the sink of Death Valley. There is no water on this road for about 38 miles, until Bennet's Wells are reached, but water may be obtained at mining camps at several points on the northern road, which leads to Ballarat.

66. *Hidden Springs, San Bernardino County (H-5).*—These springs are near the crest of the Quail Mountains, a range about 12 miles long, lying east of Brown Mountain and north of Leach Mountain. The springs are on trails known only to prospectors. They are found by following the trails of wild burros that go to them to drink.

67. *Quail Springs, San Bernardino County (H-5).*—These small springs are also in the Quail Mountains, almost due north of Leach's Spring (No. 69). They are high up in the range, away from all roads and trails, and are visited only by prospectors. The water is cold and good. They should not be confused with No. 62, which is another group of small springs of the same name, about 35 miles to the west.

68. *Fourth of July Springs, San Bernardino County (H-5).*—These form the third group of springs reported to exist in Quail Mountains. They are on the north side of the range, about 7 miles north of Leach's Spring. There is no road and no well-defined trail to them, but it is said that prospectors are able to get water for themselves and their pack animals here.

69. *Leach's Spring, San Bernardino County (H-5).*—Leach's Spring (elevation about 3,534 feet) is one of the most important camping places on the road from Randsburg to South Death Valley and to points in Nevada by way of Saratoga Springs to Resting Springs, and its water is the best to be found between Saratoga Springs and Granite Wells. Travelers are advised to make a dry camp for one night between Granite Wells and Leach's Spring. In approaching the spring from the west one ascends a steep grade through deep sand, where teams often have to double for 3 miles or more. When the summit of this grade is reached a plain road is seen leading to the right—that is, to the south—into the mountains. This road ascends steeply nearly to the main summit. At the foot of the granite pinnacles that form the axis of the range there are a few acres covered with camp

débris. Directly south of the camp is a granite boulder over 60 feet high, which bears a striking resemblance to an elephant's head, trunk, and forefeet, stationed as if the animal were looking directly north. The locality may be further identified by the Indian arrowheads of flint and obsidian that strew the ground. The spring is in a little canyon to the west, perhaps 60 feet lower than the camping place and about 100 yards from it. Its position was once marked by a lone cottonwood tree, but this has been cut down. Four or five barrels may easily be filled in one night from this spring, and other springs are to be found for a distance of about 500 feet up the canyon. Water was once piped from the spring down to the main road for the use of the borax teams from Death Valley, and there are ruins of two corrals along this old pipe line, but there is no water near them.

On leaving the spring eastbound toward Death Valley, the traveler should follow the road down a dry wash to a dry lake, where he should turn northward along the west side of the lake, until he reaches a low divide. Owl Springs (No. 70) lie about 2 miles north of this divide. On approaching Owl Springs from the south he should keep to the main road. Several persons have been lost by turning eastward at the summit, on a road that is less plain than the one that leads to the springs.

70. *Owl Springs, San Bernardino County (H-6).*—Owl Springs are about 2 miles north of the pass between the Owl Mountains and the Avawatz Mountains. They are about 17 miles by road from Leach's Spring and about 18 miles southwest of Saratoga Springs (No. 74), and furnish the only water to be obtained between these two places. On leaving Leach's Spring the road passes along the west edge of a dry lake, beyond which it climbs a low divide at the west end of the Avawatz Range. On reaching the summit the road starts down the main wash to the north, and follows it nearly to the springs, turning to the left, or west, at the foot of the Owl Mountains proper. The springs are easily found, as they are at the foot of a monument of stones about 3 feet high, placed to mark the corners of mineral claims, and the area round about them is littered by the débris of many camps. The springs are about 6 feet deep, and the water is not too saline for comfort. A short distance to the west is a trench about 25 feet long and 10 feet deep at the deeper end. The water from this trench is in larger amount and of better quality than that of the original springs. Water can be had almost anywhere around this point, for a distance of at least 300 feet north and south, by digging shallow wells.

The road northeastward to Saratoga Springs is sometimes obscured by washouts. Death Valley is in plain sight, however, and if, after following the wash for about 10 miles, the traveler can not find the road, he should keep to the right-hand side of it until he finds a

road running directly east. This road crosses a low spur of the mountains and is the best route to Saratoga Springs. The traveler may keep on down the wash to the main valley, but will find very heavy sand and rough driving, and may be compelled to return to the southeast along the foot of the Avawatz Range until he finds the right road. In attempting to cross the Amargosa River directly below this road the traveler is in danger of getting into soft and treacherous ground.

71. *Brook Spring, San Bernardino County (H-6).*—There is a small spring at the north end of the pass between the Avawatz Mountains and Leach Mountain, to which there is no road. A wagon can be driven to it from the Leach Spring and Owl Springs road by turning off at the dry lake and going southeastward up the wash. The spring is plainly marked by the litter of prospectors' camps.

72. *Valley Springs (South Death Valley), San Bernardino County (H-6).*—Strong springs boil up in a marsh about 8 miles northwest of Saratoga Springs. Their waters are so salt as to be unfit for use. As the springs form a clear, sparkling stream for a short distance before the waters sink again, travelers are inclined to let their stock drink from them. These springs can be seen from the road that leads from Death Valley toward the sink. The ground about them appears to be firm, and in most places will support a light wagon, but it is really only a crust underlain by a deep ooze in which both men and teams may sink. There is nothing in the appearance of the ground about these dangerous spots to give warning of their nature, hence the only safe rule, when traveling in the valley away from the main trails, is to test carefully all moist areas and all ground near springs with some sort of sounding rod before walking or driving upon it.

The springs are probably nothing more than a part of Amargosa River coming to the surface, as a rock reef extends across the valley half a mile below them. The volume of water supports this view.

An analysis of the water made by Thomas Price, of San Francisco, gives the following results:

Analysis of water from Valley Springs.^a

Sodium (Na).....	29, 313
Potassium (K).....	1, 198
Chlorine (Cl).....	20, 182
Carbonate radicle (CO ₃).....	16, 690
Sulphate radicle (SO ₄).....	7, 532
Hydrogen sulphide (H ₂ S).....	346
Silica	240
Organic matter.....	223

^a Expressed by analyst in grains per gallon and hypothetical combinations; recomputed to parts per million and ionic form at U. S. Geol. Survey.

73. *Cave Springs, San Bernardino County* (H-6).—Cave Springs (elevation about 6,290 feet) are a well-known stopping place on the road from Daggett to Death Valley, and the water here is the last to be had before going down into the valley. The springs are near the summit of the Avawatz Mountains, and, as their name indicates, they are found in large grottos or caves. As all travelers stop here, the majority of them camping over night, the place is clearly marked by camp litter. There are two springs, each about 5 feet across and each containing about 5 feet of water. They have been cleaned out and boarded up, but are not provided with a pump. The water is excellent.

It is about 12 miles by road north from Cave Springs to Saratoga Springs in Death Valley and about 30 miles south to Garlic Spring (No. 135).

74. *Saratoga Springs, San Bernardino County* (H7).—Saratoga Springs (elevation 362 feet), situated about 20 miles west of Dumont, on the Tonopah and Tidewater Railroad, are well known to every traveler to Death Valley, as their site is the principal camping point each winter for prospectors who have claims in the vicinity. They are at the southwest edge of a black point of the Black Mountains that projects southward into the valley. The slope of the mountains east of this point is covered with sand and recedes to the north in a large cove, but part of the range that lies immediately back (northeast) of the springs is rugged and rocky. The springs can not easily be distinguished at a distance, for their location is marked mainly by the tules growing around them, and by prospectors' stone houses, which are nearly of the color of the surrounding rocks, and on approaching from the south they are hidden by a point of rocks until one is within a few yards of them.

The springs proper form a pool about 25 feet in diameter and 4 feet deep. The bottom is of white sand, which is kept in constant motion by the rising water. The overflow from the pool forms a little stream that runs northward into shallow lakes, covering 10 or 15 acres, and surrounded by tules. One might travel along the road leading from the springs northwestward to the Old Ibex mine without suspecting the existence of these lakes, as they are concealed by ridges of sand. In winter many ducks and geese may be found here, a fact appreciated by prospectors.

Even in the coldest weather the water of Saratoga Springs has a temperature of 80° or 85°; hence the springs make a bathing pool that is delightfully refreshing after long days of weary travel over the desert. It is worthy of note that the water is full of small fish, up to about 2½ inches long, of a grayish-black color. Similar fish are found at Pahrump and in other desert springs.

The road from Daggett by way of Cave Springs enters Death Valley about 5 miles southeast of Saratoga. The road from Johannesburg comes in from the west, crossing the west end of the niter beds that lie along the north flank of the Avawatz Mountains. The road to Resting Springs leads from Saratoga southeastward toward Cave Springs for about 1 mile, then turns eastward past a little lava knob in the bottom of the valley and continues in this direction toward a long spur of the Black Mountains that juts into the valley. The traveler may cross the south end of the sand dunes and climb the short grade through the low sandy pass just east of the dunes, or he may go around this spur to the south. It is a steep and hard pull through the sand to the top of the pass, but beyond the top the trail northeastward across the flat to Amargosa River is firm and no rougher than the rest of the valley. The right-hand road has no grades, as it passes around the southern end of the ridge. It crosses the Amargosa River where the latter passes close between the point of the ridge and a black butte that lies as a southeastern extension of the ridge. Thence the road swings northeastward and joins the other branch. When Amargosa River is reached it should be followed up to the canyon, where the roads are plainly marked, and thence past Sperry to the China ranch. Another road leads from Saratoga Springs northward to the summit of the Black Mountains, passing the Ibex mine, and then turning east to Resting Springs; but this road has steep grades, is very rocky in places, and in other places is covered with deep sand. The road up Amargosa Canyon is to be preferred. There is also a dim trail along the south flank of the Black Mountains, leading to the sink of Death Valley, but no water is to be had on it, except at Confidence Springs (No. 49), until one reaches Bennet's Wells, a distance of about 50 miles.

75. *Salt Spring, San Bernardino County* (H-7).—This spring of nonpotable water is in the canyon of the south branch of Amargosa River, at the east end of South Death Valley, at an elevation of 300 feet, 5 miles southwest of Dumont, on the Tonopah and Tidewater Railroad. This canyon is the pass between the Kingston and Avawatz mountains, about 14 miles southeast of Saratoga Springs. On the south side of a spur of the Kingston Mountains are the ruins of the camp of the old Amargosa gold mine, in plain view of travelers approaching from the south.

At the old mine there is a little canyon that descends sharply to the north, in which there are the ruins of a 20-stamp mill. Near the mill are two wells, protected by curbing and covered, from which water of fairly good quality may be had. This is an important thing to know, for the waters of Salt Spring are unsafe and several persons have perished from drinking them. They are supposed by miners to contain arsenic. An analysis shows, however, that al-

though they contain no arsenic they do contain very large amounts of sodium and magnesium sulphates, being in fact an almost saturated solution of Glauber and Epsom salts. Men delirious from thirst, whose sense of taste is nearly lost, may easily drink so heartily of these waters as to produce fatal results. Several other springs on the desert that are reputed to contain arsenic are similar in character.

The road from Salt Spring northward to the canyon of the Amargosa and to China ranch is covered with deep sand, very difficult to cross. The only water to be had along it is that of the Amargosa River, when it flows this far south, or at Sperry railroad station, until the ranch is reached, a drive of 16 miles. The road running westward to Saratoga Springs is rough, but the writer has always preferred to go there for a night camp, returning thence to China ranch rather than to cross the heavy sands north of Salt Spring.

J. C. Frémont camped there April 28, 1844, and speaks of the place as follows: "A very poor camping place—a swampy, salty spot, with a very little unwholesome grass. The water rose in the springs entirely too salt to drink." He says also that they found "a spring of good water a few hundred yards away in the hill." This good spring is north of Salt Spring.

76. *Sweetwater Springs, San Bernardino County* (H-7).—These springs are about 9 miles northwest of Williams Well (No. 105), at the east end of the Avawatz Mountains. They are not on a main line of travel, but are used by prospectors in the Avawatz Mountains, who are said to have recently so marked their location that they can be found by others.

77. *Kingston Springs, San Bernardino County* (H-8).—These are small springs at the north end of the Shadow Mountains, about 2 miles south of Coyote Holes (No. 78). They are not on any road and there is no well-defined trail to them. The amount of water available is small, but its quality is good.

78. *Coyote Holes, San Bernardino County* (H-8).—These are brackish springs at the north end of the Shadow Mountains near the head of the divide between these mountains and the Kingston Mountains, on the road from Death Valley to Ivanpah, by way of Clark Mountain, and on the road from Daggett to Sandy, Nev., by way of Bitter Spring (No. 136). The nearest water to the southwest is at the Riggs mine (No. 106), in Silurian Mountain, about 20 miles distant. Horsethief Spring (No. 79) is west of the road at the north end of the pass through the Kingston Mountains. There are also springs (No. 77) about 2 miles south, near the north end of the Shadow Mountains, but they are difficult to find. There is still another spring about 7 miles to the southeast, which may be reached by a dim road along the north side of the Shadow Mountains. Another watering

place of the same name, now seldom used (No. 209), lies far to the south at the east base of the San Bernardino Mountains.

79. *Horse thief Spring, San Bernardino County (H-8).*—This spring, elevation 5,600 feet, is located in the pass between the Kingston Mountains and Clark Mountain, on the road that runs from the Williams Well (No. 105) past Coyote Holes. At Coyote Holes the roads branch, one branch leading northeastward by way of Horse thief Spring to points in Nevada, the other going south of Clark Mountain to the town of Ivanpah. The road that passes this spring is very stony and rarely traveled, but the position of the spring is clearly indicated by camp litter. The spring is in shale and the water is of good quality.

80. *Cunningham Spring, San Bernardino County (H-8).*—This is a small spring on the northeast border of the Shadow Mountains, about 6 miles southeast of Coyote Holes, on the road from the latter, by way of Clark Mountain, to Ivanpah. The water is good and the location is marked by the evidences of old camps.

81. *Pachanca Springs, San Bernardino County (H-9).*—These are small springs along the northwest base of Clark Mountain. They are away from all main roads and are used only by prospectors in that range. They are not easily found without a guide.

82. *Ricardo, Kern County (I-1).*—Ricardo is the Spanish name of a ranch in Redrock Canyon on the road from Mohave to Owens Lake, where travelers sometimes stop for water.

84. *Kane Springs, Kern County (I-2).*—Kane Springs are on the west side of Kane Dry Lake and appear on some maps as the Keehn Well. The locality is a station on the stage road from Mohave to Randsburg, by way of Water station, which is about 15 miles southwest. Garlock station is about 9 miles northeast. The water of Kane Springs is slightly brackish. Kane's Wells lie south of east from these springs on a road between Barstow and Coolgardie.

85. *Garlock, Kern County (I-2).*—Garlock post-office is at the south end of the El Paso Range on the stage road from Mohave to Randsburg, by way of Water station and Kane Lake. It is a general supply point for travelers and prospectors. From this point the road begins to ascend heavy grades to Randsburg, 12 miles distant. It is therefore a favorite camping place for those with heavy loads. The water is abundant, and supplies can be obtained at the ranch. Kane Springs and Kane Dry Lake are about 9 miles southwest.

86. *Haggin Well, Kern County (I-2).*—The Haggin ranch is on the wagon road from Randsburg northwest to Freeman, about 10 miles northwest of Johannesburg, 15 miles southeast of Freeman, and 1 mile northwest of Willow Springs (No. 87), at an elevation of about 3,350 feet (U. S. Geological Survey). On this ranch there is a well that supplies good water.

87. *Willow Springs, Kern County (I-2).*—These springs are at the east end of the El Paso Mountains, about 1 mile southeast of Haggin Well and about 10 miles northwest from Randsburg, on the road to Freeman, at an elevation of about 3,850 feet (U. S. Geological Survey). On account of their proximity to the Haggin ranch, the usual stopping place for travelers in this vicinity, the springs are unimportant except to local prospectors.

88. *Summit Diggings, San Bernardino County (I-3).*—This is a small placer camp about 6 miles north of Johannesburg, on the stage road to the Panamint Valley. The camp is well supplied with water by local springs.

89. *Skilling Wells, San Bernardino County (I-3).*—This is a group of privately owned wells about 4 miles northeast of Johannesburg, near the City Wells. The water is used to supply Johannesburg and Randsburg.

90. *City Wells, San Bernardino County (I-3).*—This is a group of drilled wells on the southwest flank of Klinker Mountain, about 5 miles northeast of Johannesburg, at an elevation of 3,400 feet. Some of the wells are supplied with windmills, others have steam pumps, and the water forms the principal part of the supply for Johannesburg and Randsburg. The house and windmills make a prominent landmark, which can be seen for 3 or 4 miles. A telephone line connects the city and the wells. The stage road from Johannesburg north to Ballarat passes nearly 3 miles west of the wells. The road from Johannesburg to Pilot Peak approaches within half a mile of them, then turns down a canyon to the southeast toward Willard Dry Lake. (See Blackwater Well. No. 95.)

91. *Squaw Spring, San Bernardino County (I-3).*—This spring is about 4 miles due east of Johannesburg, at an elevation of 3,475 feet, and is most easily reached by going from Johannesburg eastward to the City Wells, then southeastward on the Pilot Peak road to the head of the canyon just below the City Wells. There a plain road skirting the side of the mountain to the south leads to the Squaw Spring. It is not on a main line of travel and is used only by local prospectors. The water is good.

92. *Blackhawk Well, San Bernardino County (I-3).*—Blackhawk Well, elevation 2,665 feet (U. S. Geological Survey), lies at the south end of Red Mountain, about $6\frac{1}{2}$ miles northeast of St. Elmo and about 11 miles by road southeast of Johannesburg. After leaving Johannesburg, on the Pilot Peak road, a road that leads to Blackhawk Well turns to the south beyond the City Wells. The well is not in general use by travelers, because it is not on a main road, but it is occasionally used by those who go from Johannesburg to Barstow by way of Fremont's Peak and the Black Range. The water is excellent, and miners haul it to their camps.

93. *Bedrock Spring, San Bernardino County (I-3).*—This small but excellent spring is on the north side of Klinker Mountain on the old wagon road from Johannesburg through Bedrock Canyon to Searles Lake, about 10 miles northeast of Johannesburg, at an elevation of 3,225 feet (U. S. Geological Survey). This road is rarely used except by freighters who are well acquainted with the country, because no water can be obtained along it for a stretch of 30 miles or more. Travelers are advised to follow the main road by way of Searles post-office.

94. *Well at Willard Lake, San Bernardino County (I-3).*—This is a well that was dug years ago at the northeast end of Willard Dry Lake, alongside the old Death Valley borax road, at an elevation of about 2,520 feet. It gave a good supply of slightly brackish water. The well is now partially caved in and should be cleaned out. It is not on any of the main lines of travel, but is some distance south of the road from Johannesburg to Blackwater well.

95. *Blackwater Well, San Bernardino County (I-4).*—This well is one of the important camping and watering places on the main road from Johannesburg to Death Valley and Resting Springs. It is on a divide about 18 miles east of Johannesburg. The road eastward from the town runs past the railroad roundhouse toward the City Wells, which can be seen toward the northeast. About 2 miles from Johannesburg it forks; the left branch, bearing to the north, goes to Ballarat via Searles Lake; the right-hand branch runs directly toward the City Wells, and when nearly south of them turns down the canyon to the southeast. At the foot of the hill this road runs eastward to the base of Lava Mountain and north of Willard Dry Lake. In the distance a low ridge is seen, lying at right angles to the road—that is, in a north-south direction. Blackwater Well lies nearly at the crest of this ridge. The main road crosses several of the old Death Valley borax-works roads, which come in from the south in the direction of the dry lake, and these roads must be avoided, as there is no water on them for 25 miles in either direction. When the summit is reached the well can be located by the bare ground in its neighborhood, from which campers have stripped all vegetation. The well, which was dug years ago by government troops, is about 15 feet deep and is in the form of a shaft, 5 by 7 feet. The water in it is usually from 2 to 3 feet deep. When the well has not been used for a long time the water becomes dark colored and ill smelling and is often foul from the bodies of desert rats and rabbits, but when freshly cleaned it is sweet and wholesome and free from alkali. It is probable that if the well were deepened a much more abundant supply would be procured. Water was at one time piped down the slope for a distance of one-half mile to the old Death Valley borax-works road. The remnants of the trenches and pipes aid in locating the well.

A road that turns off at the wells crosses the divide to the east and extends to Copper City, a small mining camp. The road to Death Valley starts northward from the well, reaching the summit in about one-half mile, and the north end of a black lava ridge in about 3 miles. There it turns east directly toward Pilot Peak. From the foot of the lava point it is a heavy climb for 6 miles up the mountain to the base of Pilot Peak, where Granite Wells are located.

96. *Granite Wells, San Bernardino County (I-4).*—One of the best-known camping and watering places on the road to Panamint and Death Valley is at Granite Wells, just west of Pilot Peak, a very prominent landmark in the Mohave Desert. At the base of the peak is a knob of gray granite, north of which are a frame house and the remnants of several stone structures. The best water is found in a short tunnel run into the granite 50 feet northeast of the cabin. At the end of this tunnel is a sump hole, about 3 feet deep, in which the water collects. This water, coming from the granite, is cool and pure, but the sump often needs cleaning out. About 2 barrels can be got here in twenty-four hours. A quarter of a mile down the hill southeast of the granite knob are an old well and an open earth cut that was made to develop water. This cut is just east of the well and may be clogged with sand, but it can be cleaned out in a few hours, and several barrels of water sufficiently good for stock will collect during the night.

From the wells the road passes northward over a low divide and then down to the foot of the Slate Range, meanwhile keeping just west of a long ridge formed by a flow of lava. At the north end of this ridge, which is known as Black Point, the road turns eastward to Slate Range Dry Lake. There the Panamint road branches northward to Lone Willow Spring, while the road to Nevada and South Death Valley runs eastward to Leach's Spring.

There are many dim roads that turn off westward toward the Slate Range and Searles Lake, but no water is to be found along them and they are not plainly marked, whereas the main roads described are well marked.

On the road to Ballarat and the Panamint Valley there is no water to be had until Lone Willow Spring is reached, high up in the pass between the Slate Mountains and Brown Mountain, a distance of nearly 30 miles over a road that is both sandy and rocky.

The road to Death Valley by Leach's Spring is good up to a point within 6 miles of the spring, but this last 6 miles is all upgrade through exceptionally deep sand. Therefore one should travel as far as possible from Granite Wells, make a dry camp, and pull up the grade to the spring early in the morning.

97. *Pilot Spring, San Bernardino County (I-4).*—This spring is between 3 and 4 miles southeast of Granite Wells, near the top of the

hill on the old road to Copper City. The water supply is small and the spring is often choked up, because it is rarely used.

98. *Lead Spring, San Bernardino County* (I-4).—This is a small spring discovered by prospectors who found outcrops of lead ore near it. It is about 4 miles southeast of Black Point, a dark lava knob at the north end of the Pilot Peak Range, where the road from Granite Wells to Leach's Spring turns to the east. In 1904 there was at this point a guideboard that gave directions for finding the spring.

99. *Wheeler Spring, San Bernardino County* (I-6).—This spring is at the south end of Leach Mountain, in the pass between this mountain and the Avawatz Mountains. Brook Spring is 3 miles to the north and Whitney Spring (No. 100) is 5 miles to the southeast. None of these springs is on a main road. They are used only by prospectors and can be located only by the débris of former camps near the dim trail that runs through this pass.

100. *Whitney Spring, San Bernardino County* (I-6).—This spring lies about 5 miles southeast of the pass between Leach Mountain and the Avawatz Range. It is on the north side of Granite Mountains near their base, and the water rises from the granite. The supply is not large but the quality is excellent. Wheeler Spring is about 5 miles northwest and Cave Springs are about 12 miles northeast. There are no good roads or trails to this spring, but it may be found by following the dim trail that leads through the pass at the east end of Leach Mountain.

101. *Government well at Tiefert Mountain, San Bernardino County* (I-6).—It is said that there is still in existence an old well dug by government troops years ago, near the northeast edge of "No. 4 Dry Lake," about 9 miles north of Langford Well (No. 134) and about 5 miles northeast of Garlic Spring (No. 135). This old well is on the road from Daggett to Death Valley, at the southwest end of Tiefert Mountain, and is the only watering place the traveler finds along this road until he reaches Cave Springs, a distance of about 25 miles. The well is reported by recent travelers to have been partly filled by wash carried over it during cloud-bursts, so that water can not be obtained without practically redigging it.

102. *Harper's camps, San Bernardino County* (I-7).—These mining camps are in the south end of the Avawatz Range. A well-traveled road leads to them, branching off the Silver Lake road to Crackerjack, where it crosses the old Mormon trail. This point is about 7 miles northwest of Silver Lake, and is marked by a plain signboard. The road runs northwestward up the flank of the mountain to the largest canyon, and follows up this canyon to the north.

About 4 miles up the canyon the road forks again, the point being marked by a sign reading "Harper's south camp 1 mile" and "Har-

per's north camp 4 miles." Arrows on the signboard indicate the roads.

At the south camp water has been developed by tunneling into the granite. The supply is about 4 miner's inches and is excellent in quality. The north camp is in Arrastre Gulch, where there is a large supply bubbling up from beneath limestones. Arrastre Gulch is the main canyon opening onto the desert at the east end, almost due west of the siding at Riggs, on the Tonopah and Tidewater Railroad.

103. *Tomaso Springs, San Bernardino County (I-7).*—This group of springs lies at the northwest end of the Soda Lake Mountains, about 10 miles northeast of Bitter Spring (No. 136), on the old emigrant road to Salt Lake. Their permanency is indicated by the fact that J. C. Frémont mentions them in his journal. He camped here on his homeward journey from California April 25, 1844, and reported that he found the springs "dug out by the Indians or travelers" and "the waters cool and refreshing." The site of the springs is well marked by camp débris, and the water is good.

104. *Silver Lake, San Bernardino County (I-8).*—This town, on the Tonopah and Tidewater Railroad, is 40 or 50 miles north of Ludlow, on the Santa Fe Railway. It is the supply point for the Crackerjack, Chisholm, Harper, and other mining districts to the east and west. Stages and automobiles run to Crackerjack. Silver Lake has post-office, express, and telegraph offices. The railroad company pumps water from a well about 200 feet deep and pipes it through the town. The water is slightly brackish, but is used freely by everyone. The lake from which the town takes its name is about one-fourth of a mile to the west. It is a shallow, intermittent body of water, formed in a bowl in the desert by the overflow of Mohave River during seasons of unusually high water. Shallow wells sunk near the edge of this lake give an abundant supply of brackish water.

105. *Williams Well, San Bernardino County (I-8).*—There is a well at the edge of Silurian Dry Lake, west of the Riggs mine and well, on the road that leads from Daggett and Soda Lake northward to Death Valley and northeastward to points in Nevada by way of the Kingston Mountains. From this point it is about 25 miles by road southward to Government Well, at Soda Lake (No. 139), and about 20 miles southwestward to Tomaso Springs. Miners here and at Riggs can give information about trails and conditions of water supply farther north.

106. *Riggs Well, San Bernardino County (I-8).*—There is an excellent well at the Riggs gold mine, 2 miles east of Riggs station, on the Tonopah and Tidewater Railroad, and near the east end of Silurian Mountain, a small range lying between the Avawatz and the Shadow mountains. The mine has been in operation for some time

and the camp is a stopping place for all travelers. The road to the camp from Daggett, instead of going by way of Coyote Lake, crosses the east end of Alvord Mountain and goes on by way of Bitter Spring to the east end of the Avawatz Mountains, where it joins the road from Balch on the Salt Lake route. The latter road runs northward from Balch, past Government Well at Soda Lake.

107. *Toltec, San Bernardino County (I-8).*—This is a camp occupied by some turquoise miners. It is at the south end of Shadow Mountains, and about 6 miles northeast of Halloran Springs. The camp is supplied with good water, which comes from springs in the mountains near by.

108. *Halloran Springs, San Bernardino County (I-8).*—Halloran Springs have been for years a camping place for travelers en route from Soda Lake to Ivanpah Mountain and Clark Mountain over the old Ivanpah trail. The springs are near the north end of a little unnamed butte that lies about 10 miles northeast of Dante Spring (No. 140), and are readily located by the quantities of camp rubbish in the vicinity.

109. *Spring, San Bernardino County (I-8).*—Several desert prospectors have reported that there is a spring about 8 miles southeast of Halloran Springs, and that the water is good, but there are no traveled roads or trails to it.

110. *Crater Spring, San Bernardino County (I-9).*—There are said to be springs at the Three Ash Craters, a prominent group of extinct volcanoes in the desert at this point. They are not near the main traveled roads and are visited only by prospectors. No accurate description of them has been obtained.

111. *Valley Wells, San Bernardino County (I-9).*—Valley Wells, known also as Rosalie Wells, are situated near the border of Ivanpah Mountain, on the main road from Soda Lake and from Kessler Springs (No. 112) to the old copper mine in Ivanpah Mountain. The wells were dug by a mining company and supplied enough water to operate the smelters that were once in use on the copper ores of the district.

112. *Kessler Springs, San Bernardino County (I-9).*—Kessler Springs, elevation 5,500 feet, are well known to most desert travelers as they are on the old road from Daggett by way of Soda Lake to the New York Mountains. They are at the south end of Ivanpah Mountain, about 6 miles northwest of Cima station, on the Salt Lake Railroad. A road leads from them to the town of Ivanpah, about 10 miles northeast, and to Rosalie, about 12 miles northwest. The water is abundant and excellent.

113. *Cottonwood Spring, San Bernardino County (I-10).*—The spring is on the north side of the New York Mountains, near the Salt Lake Railroad, and is used principally by miners and pack

pectors in this region, as it is not on any main line of desert travel. There are several springs of this name in the area discussed, so that the name alone is not distinctive. About 30 miles to the southwest are Cottonwood Springs (No. 162), which are also used as a watering place.

115. *Ivanpah Well, San Bernardino County (I-10).*—A well has been dug in the bottom of the south end of Ivanpah Dry Lake, about a mile east of the town of Ivanpah, at an elevation of 4,230 feet (Santa Fe Railway). The town is the present terminus of the Santa Fe branch road from Goffs. This well formerly supplied a stage station on the old road from Barnwell, Cal., to Manse, Nev. It is about 140 feet deep and is provided with a windlass for drawing water. The water is only slightly saline. It is still used by those who drive north from Barnwell.

116. *Saccatone Springs, San Bernardino County (I-10).*—These are small springs on the north side of the New York Mountains and are of importance only to local prospectors and miners, as this region is so thickly settled now as to offer no difficulties to the traveler.

117. *Water Station, Kern County (J-1).*—This is a well-known road ranch and old stage station, about 9 miles northeast of Mohave, on the road from Mohave to Keeler. Good ranch houses, an abundance of water, and accommodations for travelers will be found at the station.

Frémont stopped at the springs here early in April, 1844, on his way from Cameron Salt Lake east by way of the "Desert Buttes" to Mohave River.

118. *Desert Wells, Kern County (J-2).*—This is an old stage station on the Mohave and Randsburg stage road about 6 miles northeast of Water station, and 15 miles from Mohave, the junction of the Southern Pacific and Santa Fe railroads. A road runs eastward from these wells to Francis Well (No. 119), on the railroad from Kramer to Randsburg.

119. *Francis Well, San Bernardino County (J-3).*—This is a drilled well, equipped with a pumping plant, on the railroad between Kramer and Johannesburg, about 12 miles north of Kramer, at an elevation of 4,220 feet (Santa Fe Railway). It is a watering place for travelers from Mohave by way of Desert Wells and for those going by team from Kramer to the mines farther north.

120. *Goleta Spring, San Bernardino County (J-3).*—At the southeast base of Fremont Peak there is a spring whose name dates back to the time of Frémont's last homeward trip across the Mohave Desert. It is just west of the old road that runs from Randsburg to Barstow by way of Harper Dry Lake and Black ranch (No. 123). Another old road branches from this main road about 3 miles west of Harper Lake and runs southward to Harper station, on the Santa Fe

Railway. There has been very little travel over any of these roads for a number of years.

121. *Star Springs, San Bernardino County (J-4).*—These springs are about 3 miles east of the south end of Fremont Peak, on the east side of the pass through which the road from St. Elmo to Harper runs. They are along the west base of the Black Range. As there is good water at Goleta Spring, on the wagon road directly west, the Star Springs are not important to travelers.

122. *Grant Springs, San Bernardino County (J-4).*—There are reported to be good springs at the Grant Corral, $1\frac{1}{2}$ miles northwest of the Black ranch, on the old San Bernardino and Panamint road, at the point where it passes Harper Lake. The springs are between Harper Lake and the low range of mountains to the north. As there is a good supply of water at Black's Well (No. 123), these springs are not important.

123. *Black's Well, San Bernardino County (J-4).*—This well is about 7 miles northwest of Hinkley, at the east end of Harper Lake, on the old road from Victorville and Hinkley stations to Death Valley formerly known as the San Bernardino and Panamint road. An adobe house, which served as the headquarters of an old cattle ranch, is still standing near the well and is in good condition. The well is covered with a platform and the water stands within a few feet of the top. It is dark colored, but nearly free from saline matter.

The cottonwood trees that surround the well and house can be seen from a distance of several miles and serve to guide the traveler to the water. To the northwest, across Harper Lake, no water is to be had until one reaches Fremont Peak, but toward the north water may be obtained at the mining camps in the Black Mountains.

124. *Murphy's Well, San Bernardino County (J-4).*—This well is at the Murphy Dry-Placer Camp, about 15 miles northwest of Barstow and about 6 miles southwest of Coolgardie. Directions for finding it are not easily given, because this region for miles around has been gridironed with roads and trails over which the miners haul water to their placer camps. It is on one of the roads from Barstow to Copper City, and usually there are miners at some of the placer workings who can direct travelers to the well.

126. *Coolgardie, San Bernardino County (J-5).*—Coolgardie is the name of a small mining settlement, the cabins of the miners being scattered over several square miles of dry-placer workings. Water may be procured at the camp from the miners, who bring it in from the springs near by. The road to Coolgardie is the left-hand or west branch on the second summit north of Barstow and west of Kane's Wells (No. 129). The right-hand road at this point leads east to Kane's Wells.

127. *Well, San Bernardino County (J-5).*—This well is at the southwest end of Coolgardie Lake, the easternmost of the three dry lakes in this township. It is by the side of the road to Copper City and is readily found. The well is dug in the playa deposits and the water is of fair quality, being only slightly brackish.

128. *Indian Spring, San Bernardino County (J-5).*—This spring is about 12 miles north of Kane's Wells (No. 129) and about 4 miles north of some dry-placer mines. A road leads northward to it from Kane's Wells and thence westward by way of Coolgardie Dry Lake to Copper City, but it is a road over which there is but little travel. The spring is utilized by miners who work the dry gold placers of that region. The water is better than that along the dry lakes to the southwest, as it flows from granite. Another Indian Spring (No. 150) lies about 75 miles westward, near Rosamond Station, on the Southern Pacific Railroad.

129. *Kane's Wells, San Bernardino County (J-5).*—These wells (Pl. III, A) are about 22 miles north of Barstow on the road to Coolgardie and Copper City. After leaving Barstow the road crosses two divides, and a short distance beyond the second divide turns north-eastward to the head of a little canyon that runs eastward. Kane's stamp mill and wells are about one-fourth mile down this canyon and can not be seen by the traveler until he is near the house and the mill. There are two good wells here, both boarded up and supplied with pumps.

On looking down the canyon from the mill the traveler may see Coyote Dry Lake in the desert below, but to reach this lake or to go northward he should return to the head of the canyon. The main road leads northward from this point past the placer camps to Indian Spring and Copper City; the middle road at the summit leads north-westward to Coolgardie, about 7 miles distant. On continuing northward and following the crest of the divide on the easternmost trail, the traveler will find a road that turns eastward down the canyon. This road leads to Coyote Dry Lake. On the main Copper City road to the north, beyond the dry placer works, another road turns off toward the east, running to Paradise Springs (No. 130), but it was so badly washed out by cloud-bursts in 1905 as to make these springs difficult to find. Kane Springs (No. 84) lie west of Randsburg, while Kane's Spring (No. 176) is about 9 miles southeast of Newberry Station.

130. *Paradise Springs, San Bernardino County (J-5).*—Paradise Springs are a favorite stopping place with prospectors who know the way to them, as there is generally sufficient grass around them to afford good grazing. The best way to reach them from Kane's Wells is to follow the road from that place directly north for about 3

miles—that is, to a point about 1 mile north of the dry-placer camp. The road then turns to the east and descends along a dry wash to the foot of the main range. Here it turns to the north across a wide flat and curves finally into a large cove, in which the springs are found. The water is clear, pure, and warm, and the developed supply amounts to 2 or 3 miner's inches.

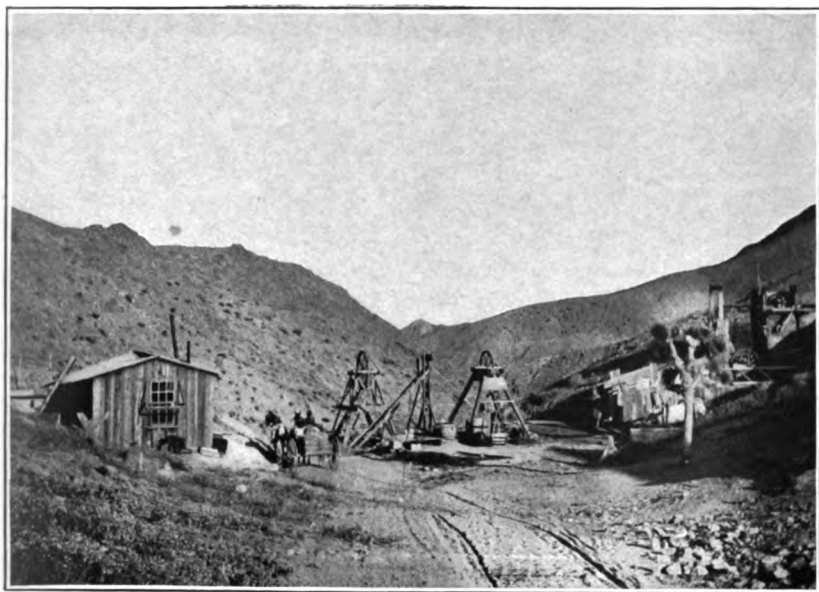
A water appropriation has been filed on the springs by the Paradise Mountain Mining and Milling Company, and a gravity pipe line laid to their workings, about 2 miles southwest.

131. *Canyon Spring, San Bernardino County (J-5).*—This spring is in a main canyon on the east side of an unnamed mountain northwest of Coyote Dry Lake. It can not be located by land lines with certainty, but it is probably in the NE. $\frac{1}{4}$ sec. 7. It is not on a main line of travel, but is near what is known as the old trail from Barstow by way of Paradise Springs to Death Valley. It is 6 miles east of Paradise Springs and about 5 miles northwest of the north end of Coyote Lake. There was once a road from Daggett along the west side of Coyote Dry Lake, which led to Canyon Spring and to Garlic Spring (No. 135). These roads are rarely traveled now by wagon and are probably obliterated for long distances by drifted sand. Usually they are less obscure near the spring than at greater distances from it. The supply of water is not large, but the quality is good.

132. *Willow Spring, San Bernardino County (J-5).*—There is a small spring of brackish water in the foothills at the north end of Coyote Lake. In 1900 water was running there in some quantity, but early in 1905 the spring could not be found, because of the effects of a storm in the vicinity some time before. It should be about 2 miles west of the main road that crosses Coyote Lake en route from Daggett to Death Valley. Its position is noted, in order that prospectors and others who traverse this country may be on the lookout for it. It often happens that springs are covered by the wash of storms and disappear temporarily, but later reappear near the old location.

133. *Coyote Well, San Bernardino County (J-5).*—Coyote Well, the first camping place on the road from Daggett to Death Valley, is about 17 miles northeast of Daggett. The traveler may go from Daggett by way of Otis and pass east of the Calico Range to the well, keeping in the open country all the way, or he may take another road which leads from Daggett northward by way of Borate. From Borate this road follows the narrow-gage railroad of the Pacific Borax Company to the divide of the Calico Mountains, then continues down the mountain slope to the main valley, where it turns eastward, following the valley to the open country, and thence northeastward to the well.

The well (Pl. III, B) is easily found, as it stands by the roadside at the south end of Coyote Dry Lake. It is about 15 feet deep and



A. KANE'S WELL.



B. COYOTE WELL.

is covered with a platform. There is a windlass and an iron pump at the well, but the pump handle was broken some time in the spring of 1905 by vandals. The water is abundant but it is slightly brackish. Small sulphur springs issue from the hills about 2 miles west of this well, but the water is small in quantity and is fit only for stock. The next water to be found on this road is about 14 miles farther north, at Langford Well (No. 134). Two other watering places, known as Coyote Holes (Nos. 78 and 209), lie about 70 miles to the northeast and to the southeast, respectively.

134. *Langford Well, San Bernardino County (J-6).*—One of the important watering places on the road from Daggett to Death Valley is a well at the southwest corner of Langford Dry Lake, about 14 miles north of Coyote Well. The water here is the best to be had between Daggett and Cave Springs. The well is about 40 feet deep and is protected by board covering. A good iron pump was put in early in 1904, but was broken in the fall of the same year by vandals. The well is readily found, as it is close by the roadside and is surrounded by the débris left by numerous camping parties.

135. *Garlic Spring, San Bernardino County (J-6).*—This is a well-known spring on the road from Daggett northward to Death Valley. It is at the west edge of the range of mountains that lies next north of Langford Dry Lake and south of Tiefert Mountain, at an elevation of about 2,455 feet. The majority of campers stop at Langford Well and do not stop at Garlic Spring, because the water there is strong with sulphur, and sodium and magnesium sulphates.

136. *Bitter Spring, San Bernardino County (J-7).*—This spring is near the southeast end of Bitter Lake, on the old emigrant road to Salt Lake City. It is the first watering place the traveler reaches on this road after passing Alvord Mountain. It is also on the road from Daggett to the Shadow Mountains, and is one of the principal stopping places on that road. It has been known since 1852. The water contains too much sodium sulphate to be wholesome, but it can be used.

137. *Cronese Spring, San Bernardino County (J-7).*—This spring is at the southeast end of Cronese Dry Lake, at the southwest base of the Soda Lake Mountains. It is well known to desert prospectors, but not being near one of the principal routes is not known to casual travelers. The water is slightly brackish but not unwholesome. By digging a shallow well here enough water could probably be developed to irrigate a few acres.

138. *Barrel Spring, San Bernardino County (J-7).*—This spring, at one time an important point on the old emigrant road to Salt Lake, is near the south end of the Soda Lake Mountains, about 15 miles east of Afton and 10 miles southwest of Government Well, at

Soda Lake (No. 139). It is near a rocky point where the road from Daggett north to Government Well rounds a spur of the Soda Lake range. It is a small spring, protected by a barrel sunk in the ground. Since the building of the Salt Lake Railroad it has lost its importance to travelers.

139. *Government Well at Soda Lake, San Bernardino County (J-8).*—At Soda Lake, a station on the Tonopah and Tidewater Railroad, is one of the wells dug by government troops forty or fifty years ago. It is on the eastern branch of the old emigrant road from San Bernardino to Salt Lake City by way of Mohave River, and is near the west edge of the sink of the Mohave, at the eastern base of the Soda Lake Mountains. The well is easily found, because its position is marked by the ruins of the old adobe and stone buildings erected by the troops. The water is a part of the underflow of Mohave River, and is of fair quality, in spite of the heavy deposits of soda that whiten the surface all about it.

The well is a pool lined with stone, about 5 by 8 feet in dimensions and 3 feet deep. It is near the edge of some tules about 150 feet southeast of the largest stone building. The buildings are on the north side of a limestone knob, and the traveler can not see them from the road until he is within 100 yards of them. This knob, however, near the middle of the western edge of Soda Lake, serves as a guide to their position. The tules, which can be seen from a distance as one approaches the well, also aid in finding it.

The next water north is at Dante Springs (No. 140), on the road to Halloran Springs and Ivanpah.

A road leads northward from Government Well by way of Silver Dry Lake to Death Valley. It passes between the Avawatz and Shadow mountains, but there is no water to be had along it until one reaches Williams Well, at the west end of Silurian Mountain, a distance of about 25 miles, unless one turns off to Berry or to Silver Lake.

140. *Dante Springs, San Bernardino County (J-8).*—These springs are, as near as can be determined, in the southeast quarter of section 28. They are on the north side of the butte that stands at the northeast end of Soda Lake, on the road from Government Well, at Soda Lake, to Halloran Springs and Valley Wells (Rosalie). It is about 12 miles from Dante Springs to Halloran Springs. The water is of good quality, but its quantity is not large.

141. *Borax Well, San Bernardino County (J-8).*—This is a well dug by miners on the east side of Soda Lake, about 7 miles nearly due east of Soda Lake station. A road leading from Balch, on the Salt Lake Railroad, to Dante Springs passes it. The well is about 20 feet deep and the water is soft and of fair quality. Analysis

shows the presence of borax and of a small amount of sodium sulphate.

142. *Well near Soda Lake, San Bernardino County (J-8).*—A well is reported to exist near the south end of Soda Lake, $2\frac{1}{2}$ miles southeast of Epsom station, on the Salt Lake Railroad. The supply of water is said to be good, but the well is not of great importance, because travelers can obtain water at a more convenient point, Balch station, where most of the desert wagon roads leave the Salt Lake Railroad.

143. *Spring near Soda Lake, San Bernardino County (J-8).*—Prospectors report that there is a good spring at the north end of Old Dad Mountains, about 4 miles southeast of Balch.

144. *Marl Springs, San Bernardino County (J-9).*—There are springs of good water at the north end of a small butte about 9 miles southwest of Cima station, on the Salt Lake Railroad. They are on the old road from Kessler Springs to Soda Lake. They have been used for years by prospectors, and are marked by the traces of old camps beside the road.

145. *Government Holes, San Bernardino County (J-10).*—This watering place is 5 miles northeast of Elora, on the Salt Lake Railroad. More than forty years ago a military road extended from Fort Mohave, Ariz., across the desert to Mohave Sink and up Mohave River. This supply road passed the old Piute Springs (No. 149), the Mid Hills, and Soda Lake, and at old Camp Cady on Mohave River joined the emigrant trail from San Bernardino to Salt Lake.

One of the wells dug along this road by the troops, years ago, is known as Government Holes. The well stands at an elevation of 5,100 feet, on the west side of the Mid Hills, a range of low buttes just east of the north end of the Providence Mountains and south of the west end of the New York Mountains. The tops of the Mid Hills show granite pinnacles, and the well at their base is plainly marked, as various desert roads converge to it. The well is protected by a corral, and a ranch house stands near it. The water is very good.

146. *Out West Well, San Bernardino County (J-10).*—This is a well dug at the camp of the Out West Mining Company along the west side of the Mid Hills, about 4 miles in an air line southwest of Government Holes (Pl. II, *B*). A well-traveled wagon road leads westward from Government Holes to the head of Black Canyon and down the canyon for about 1 mile. It then turns back toward the east for a few rods and northward to the Out West camp. The camp is marked by a stone house and by the old frames of tent houses. The well is dug in granite and is protected by curbing. It is about 40 feet deep and usually contains 15 feet or more of sweet, pure water.

There is no other water to be had along a road that runs southward through Black Canyon until the old mining camp of Providence (No. 164) is reached, about 25 miles northwest of Fenner.

147. *Rock Springs, San Bernardino County (J-10).*—These springs lie 6 miles southeast of Government Holes, on the old government road running to Fort Mohave, Ariz. They are easily found and the water is of good quality, although the quantity is not large.

148. *Vontreger Springs, San Bernardino County (J-11).*—These springs are about 9 miles north of Goffs Station (Blake post-office), on the Santa Fe Railway, in the low hills east of the branch line that runs from Goffs to Barnwell, in a canyon on the south side of the summit of the hills. They are easily found, and their water is abundant and good. There is no other water on the road north of these springs until Barnwell is reached.

149. *Piute Springs, San Bernardino County (J-11).*—These are well-known springs in Piute Pass, about 15 miles north of Goffs Station, on the Santa Fe Railway. They are on the old military road that leads from Fort Mohave to Government Holes, and roads lead to them from Goffs, Ibis, and Blackburn Siding. There are other springs of the same name, about 20 miles northward, just across the state line in Nevada.

150. *Indian Spring, Kern County (K-1).*—This is a strongly flowing spring, about 3 miles northeast of Rosamond Station, on the Southern Pacific Railroad. It is near the northwest edge of Rosamond Dry Lake, on the wagon road that runs from the railroad to Buckhorn Spring (No. 152). Water fit for stock can be obtained here. There is another spring (No. 128) of the same name, on a little-traveled road between Daggett and Copper City.

151. *Rodriguez, Kern County (K-2).*—This is a pumping station on the Santa Fe Railway, 18 miles east of Mohave. The railway company has sunk a well 40 feet deep at the west edge of Rodriguez Dry Lake, and procured an abundant supply of water of fair quality.

152. *Buckhorn Spring, Kern County (K-2).*—Buckhorn Spring has been well known to desert travelers for over thirty years. It is on the west side of Rodriguez Dry Lake, about 7 miles south of Rodriguez Station, on the Santa Fe Railway, and about 15 miles east of Rosamond Station, on the Southern Pacific. A cabin belonging to a prospector who has lived there for years stands near the spring, which is therefore easily found. The water, although slightly brackish, is of fair quality. There are other springs about the lake border. One of these is about 6 miles southeast of the wells, on the east edge of the lake, the road to it passing around the margin, and another is about 3 miles north.

153. *Spring at Rodriguez Lake, Kern County (K-2).*—A spring exists on the west edge of Rodriguez Lake, about 4 miles northeast of

Buckhorn Spring. It is said to be a little salty, but it can be used by men as well as animals. It is not important, however, because Buckhorn Spring is near by.

154. *Flowing Wells, Kern County (K-2).*—Artesian wells were drilled several years ago on the east side of Rodriguez Dry Lake, 7 miles east of the Santa Fe station of the same name, about 15 miles by road southwest of Kramer, and about 7 miles northeast of Buckhorn Spring. The water is reported to be abundant and of excellent quality, and the wells are at the northeast end of a considerable area in which artesian waters have been developed.

155. *Kramer, San Bernardino County (K-3).*—Kramer (elevation 2,479 feet, according to Santa Fe Railway) is the junction point of the Santa Fe main line and the branch leading north to Randsburg and Johannesburg. It is about 174 miles from Los Angeles by way of Barstow, and 38 miles east of Mohave. The railway company has recently drilled a well at this point, and water can now be procured here by travelers. A good wagon road parallels the railway to Randsburg, on which water may be obtained at Fremont station, Francis Well, and St. Elmo. A wagon road also leads from Kramer to Victorville, about 35 miles southeast.

156. *Well at Harper Lake, San Bernardino County (K-4).*—There is a well about $1\frac{1}{2}$ miles south of Black's ranch and about one-half mile east of the road from Hinkley to Black's. The well is in an open alkali flat and was once used for watering the ranch stock. The water is brackish and the watering place is not important, for Black's Well is near by.

157. *Hinkley Well, San Bernardino County (K-4).*—Hinkley is a pumping station on the Santa Fe Railway about 10 miles west of Barstow. There is no town at this point, but the site is marked by the pump and section houses. The company has a well 70 feet deep from which to fill its tanks. The traveler may procure a supply from these.

158. *Newberry Springs, San Bernardino County (K-6).*—There are large warm springs about 600 yards south of Newberry station on the Santa Fe Railway. The water is clear and pure and is used by prospectors en route to the mountains farther south. The Santa Fe company has built a circular masonry reservoir about the springs and pumps from them through an 8-inch pipe line. The water is hauled in tank cars to supply locomotives at Ludlow and Bagdad.

160. *Willow Springs, San Bernardino County (K-9).*—These springs are at the southwest end of Granite Mountain and are marked by a clump of willow trees. They are about 20 miles northwest of Cadiz station on the Santa Fe Railway and at about the same distance southwest of Kelso station on the Salt Lake Railroad. A pros-

pector's trail leads to them from Kelso along the east side of Granite Mountain.

161. *Cove Springs, San Bernardino County (K-9).*—These springs are at the southeast edge of Granite Mountain, about 6 miles south of Cottonwood Springs (No. 162). There is a road from them to Kelso station on the Salt Lake Railroad. The quantity of water is limited, but the quality is excellent, as the springs have their source in granite. They should not be confused with Cave Springs (No. 7) in the Avawatz Mountains.

162. *Cottonwood Springs, San Bernardino County (K-9).*—These springs, which yield good water, are at the southwest end of the Providence Range, in the pass between that range and Granite Mountain. There is a road from Kelso station, on the Salt Lake Railroad, southward to the springs, which are about 15 miles by road from the station.

163. *Bonanza Well, San Bernardino County (K-9).*—This is a well sunk by the Bonanza King Mining Company about one-fourth mile northeast of the mine hoist. It is known also as the Providence Well. It is on the east side of the Providence Mountains, near the base of the principal peak of the range, about 25 miles northwest of Fenner station, on the Santa Fe Railway. The well was drilled to a depth of 250 feet, the water rising within 100 feet of the surface. It has its source, apparently, in a porous limestone. The water is of fair quality. There is no water on the road from Fenner to this well, and there is only one other watering place in the vicinity, the old Providence Wells (No. 164), at the mill, $2\frac{1}{2}$ miles to the northeast.

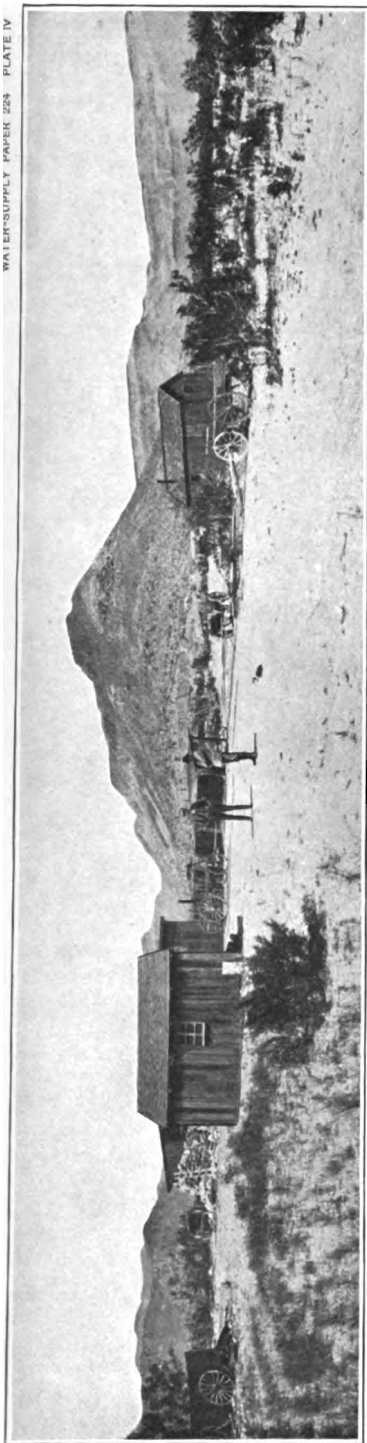
It is probable that a considerable water supply could be obtained along the east edge of this range, and that a small area might be irrigated with it by the use of pumping machinery.

There are springs of the same name at No. 180, about 18 miles to the south.

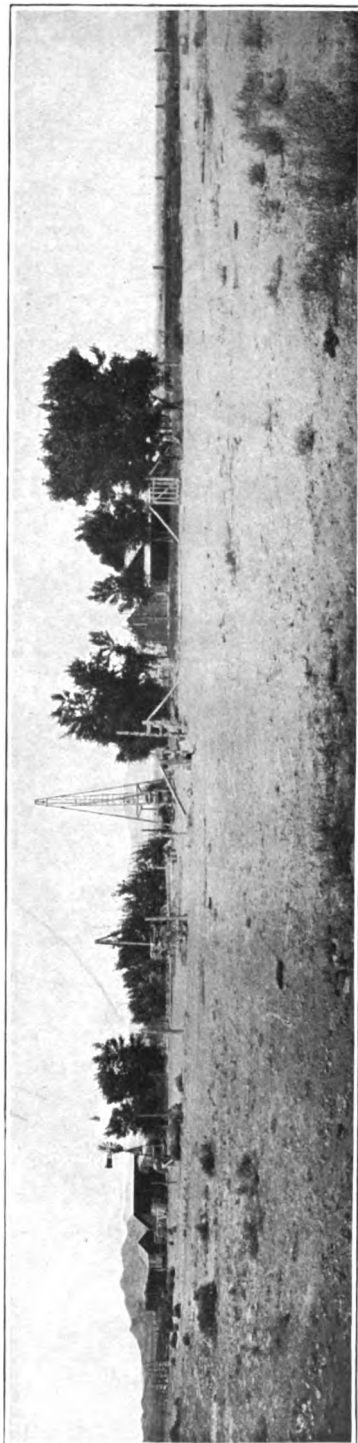
164. *Providence Wells, San Bernardino County (K-9).*—These are old wells near the east edge of Providence Mountains. Their position is marked by the ruins of a little settlement and the old silver mine of the Providence Mining Company (Pl. IV, A). Usually there are miners stopping at one of the houses of the old camp. The water from the wells is excellent, and the evidences of former rather extensive cultivation indicate that it must be present in some quantity.

165. *Fenner, San Bernardino County (K-11).*—Fenner (elevation 2,084 feet) is a settlement on the Santa Fe Railway, 269 miles east of Los Angeles. The railway company has drilled a well 500 feet deep at the station and installed a large pumping plant. The water is of good quality and the supply is large.

Fenner is the trading and supply point for the Providence Mountain and adjacent mining districts. A road leads from it north-



A. PROVIDENCE WELLS.



B. ARTESIAN WELL AT BOX S RANCH.

westward to the camp of the Bonanza Mining Company. This road, which may be seen from the station, crosses the desert in a straight line directly toward the prominent Providence Range. About 12 miles from the railway an obscure road branches from it toward the north, going past the east spur of the range. It leads up Black Canyon to Government Holes (No. 145). Near the head of Black Canyon, about 26 miles north of Fenner, on the east side of the road, can be seen the shaft houses of the Out West Gold Mining Company and the road to them. A well-defined trail leads from the shafts eastward across the ridge about a quarter of a mile, to the mining company's camp. There is no water on the main road between Fenner and Government Holes.

166. *Goffs, San Bernardino County (K-11).*—Goffs (Blake post-office) is a station on the Santa Fe Railway 279 miles east of Los Angeles. It is the junction point from which a line runs northward to Ivanpah, crossing the Salt Lake Railroad at Leastalk. The railway company has drilled a well at Goffs and has installed a pumping plant, from which water may be obtained by the traveler. A good wagon road leads from Goffs northward along the railway. Water may be obtained on this road at Vontreger Springs, about 9 miles north of Goffs.

167. *Ibis, San Bernardino County (K-12).*—Ibis is a station on the Santa Fe Railway about 296 miles from Los Angeles, just east of the summit that the railway crosses before descending to Needles. A wagon road leads northward from the station to Searchlight, and to Eldorado, Callville, and other points on Colorado River in Nevada. The railway company has drilled a well here 300 feet deep and installed a pumping plant. The water is found in cemented gravel and is of excellent quality. Ibis is merely a siding and watering station, and those who need supplies must procure them at Needles.

168. *Klinefelter, San Bernardino County (K-12).*—Klinefelter (elevation 1,445 feet, according to the Santa Fe Railway) is a station on the Santa Fe 299 miles east of Los Angeles. The railway company has installed a large pumping plant here to supply its locomotives. The water is taken from large springs that rise in the deep gravels of the Sacramento Wash. This station is the main source of supply for miners prospecting in the Sacramento Mountains, and travelers can always find water here.

169. *Needles, San Bernardino County (K-12).*—Needles (elevation 491 feet, according to the Santa Fe Railway) is in the valley of Colorado River. This city is the principal supply point for miners and prospectors in the eastern end of the Mohave Desert. The railway company has large machine shops here, and wholesale stores carry an abundance of supplies of all kinds. The water, which is

easily obtained from shallow wells, is of excellent quality, and miners going into the mountains to the north and west are advised to start from Needles with an ample supply, as there is very little to be found within a radius of 20 miles or more except along the railway and the river.

170. *Victorville, San Bernardino County (L-4).*—Victorville is on the main line of the Santa Fe Railway and is the starting point for the most important county roads running east and west along the north base of the San Gabriel and San Bernardino mountains. Mohave River, which flows through the town, is crossed here by means of a bridge, but at other points above and below it must be forded. Ordinarily this is a simple matter, but occasionally, in fall and winter, when travel on the desert is at its maximum, heavy storms in the mountains so increase the flow in the river as to render it unfordable.

The railway company has a well and pumping plant at Victorville, and artesian wells have been developed in the vicinity, so that there is always an abundance of water to be had here. The town is also an outfitting point where teams and supplies of all kinds may be procured.

171. *Colony Well, San Bernardino County (L-4).*—This well is about 9 miles east of Victorville and about $4\frac{1}{2}$ miles north of the county road that runs southeastward from the town. It was dug to supply an agricultural settlement that has recently been established in the desert. The well is about 50 feet deep and yields a limited supply of water of poor quality.

172. *Spring (no name), San Bernardino County (L-4).*—This is a spring on the south side of a western spur of Granite Mountain, about 14 miles northeast of Victorville, on the main road from Victorville to Daggett. The water is good and the place is well marked by debris left by numerous camping parties. This spring furnishes the only water to be obtained on this road between Victorville and Daggett. The main trend of Granite Mountain is north and south, but at the north end a cross ridge runs east and west. This spring is along the south edge of the western extension of this ridge.

173. *Ord Spring, San Bernardino County (L-5).*—This spring is located at the western edge of Ord Mountain, on the road that leads southward from Daggett between Ord and Granite mountains. It is an old camping place and is readily found. A road runs southward from it along the east side of Granite Mountain to the county road at Dead Man's Point, and another connects with the county road from Victorville to Daggett. The water is of good quality.

174. *Le Conte Springs, San Bernardino County (L-5).*—These springs are at the east end of Ord Mountain, about 35 miles east of Victorville and 22 miles southwest of Newberry, on the road that con-

nects these two points. The road is well traveled and the springs are plainly marked by the rubbish left by campers.

175. *Willow Springs, San Bernardino County (L-5).*—These springs are at the north end of Ord Mountain, about 5 miles in an air line north of Le Conte Springs, and about 15 miles south-southeast of Daggett. There is no road or trail leading directly to them and they are used only by prospectors who know of their location. The water is of good quality. Travelers from Victorville to Newberry Springs can obtain a supply of water at Le Conte Springs, which are much more easily found.

176. *Kane's Spring, San Bernardino County (L-6).*—There is a spring of good water at the east base of Kane Mountain, about $6\frac{1}{2}$ miles southwest of Troy station and about 9 miles by road southeast of Newberry station, on the Santa Fe Railway. The spring is on the wagon road from Victorville to Newberry by way of Dead Man's Point and Le Conte Springs.

177. *Spring (no name), San Bernardino County (L-16).*—This spring is in the pass between Bessemer Mountain and a western extension of the Bullion Mountains, about 12 miles south of Hector siding, on the Santa Fe Railway, and about 6 miles south of the road from Newberry station to Mean's Well (No. 198). It is not on any main road. The water is slightly brackish, but is used by the miners who are developing the iron deposits in Bessemer Mountain.

178. *Peacock Spring, San Bernardino County (L-7).*—This spring is at the northwest end of the Bullion Mountains, south of a dry lake. It is about 10 miles from Lavic station, on the Santa Fe Railway, by a wagon road that leads southward from Lavic to Mean's Well (No. 198) and the San Bernardino Mountains. No other water is to be had along this road until Mean's Well is reached, 15 or 20 miles farther to the southwest. The position of the spring is marked by the dry lake and by rubbish of the kind usually found at all old desert camping places.

179. *Mascot Spring, San Bernardino County (L-8).*—There is said to be a spring at the base of the lava flow near the northwest edge of Bristol Dry Lake, about $4\frac{1}{2}$ miles south of Bagdad station.

180. *Bonanza Springs, San Bernardino County (L-10).*—There are springs of good water at the south edge of Clipper Mountain, about 6 miles northwest of Danby station, on the Santa Fe Railway. A local road from Danby leads to them. They are used chiefly by prospectors in Clipper Mountain.

Bonanza well and Providence wells lie about 18 miles north of these springs.

181. *Siam, San Bernardino County (L-10).*—This is a pumping station on the Santa Fe Railway about 6 miles southwest of Danby, in a little pass at the north end of Ship Mountain through which the

railway runs. It is the first station east of Cadiz. The wells sunk by the railway company at this point are not deep, but they supply a large amount of excellent water, which is procured from underlying gravels.

182. *Danby, San Bernardino County (L-10).*—Danby (elevation 3,024 feet, according to the Santa Fe Railway) is a settlement on the line of the Santa Fe 253 miles east of Los Angeles. It is a local supply point for miners operating in Old Woman Mountain, Clipper Mountain, Danby Dry Lake, and at other places in the region. The railway company has drilled a well 637 feet deep and installed a good pumping plant, at which travelers can fill their barrels and canteens. The water is of excellent quality. A good road runs from Danby southward on the west side of Old Woman Mountain to the house built of rock salt on Danby Dry Lake, thence southward to Miller's well (No. 216), at the southwest end of the lake. From Miller's Well the road leads to the Maria Mountains, where there are mining settlements, and thence to Ehrenberg, Ariz. This is the only road southward from Danby. In 1908 a well 60 feet deep was sunk by the side of the road at the north end of Danby Lake, about 2 miles northeast of the Salt House. This well is equipped with a windlass and yields excellent water. The water of Miller's Well is not of good quality, but will serve for animals. Water is next found 15 or 20 miles beyond Miller's well at Brown's well (No. 232).

183. *Old Woman Springs, San Bernardino County (L-11).*—There are large springs in the main canyon on the east side of Old Woman Mountain, named, as is the mountain itself, from a granite pinnacle at the crest of the range. There is no regularly traveled route along the east base of this mountain, nearly all of the travel being by way of the Danby road on the west side. There is, however, a dim trail, washed out in many places, from Danby Dry Lake on the south along the base of the mountain to these springs. The water in the springs rises from granite and is pure and sweet. These springs should not be confused with those of the same name (No. 196) about 35 miles east of Victorville.

184. *Sunflower Springs, San Bernardino County (L-11).*—These springs are on the eastern border of a northern extension of Old Woman Mountain, about 12 miles in an air line southeast of Fenner. The springs are in a cove about half a mile up a canyon which intersects the mountain. There are neither roads nor regular trails to them, but they may be found by the cattle paths that lead to them. The water comes from limestone and is of good quality.

185. *Mellen, San Bernardino County (L-13).*—Mellen (elevation 420 feet, according to the Santa Fe Railway) is a station on the Santa Fe, about 9 miles southeast of Needles, near Colorado River. The railway company has sunk a well in the alluvium of the valley

and installed a pumping plant over it. It is the water-supply point for prospectors in the near-by points of the Mohave Mountains to the south and the Sacramento Mountains to the west.

186. *Burcham ranch, San Bernardino County (M-4).*—This is a well-known ranch near the head of Mohave River, in San Bernardino County, about 7 miles in an air line east of Summit station, on the Santa Fe Railway. It is reached by a road from Cajon Pass that runs through Horsethief Canyon and thence down the river. There is a horseback trail from this ranch to the head of the river and another southward into the San Bernardino Mountains. There is always flowing water in the Mohave River at the ranch.

187. *Dead Man's Lake Well, San Bernardino County (M-5).*—Dead Man's Lake is the first dry lake on the county road that leads from Victorville eastward to the Rose mine, in the San Bernardino Mountains. It is about 18 miles east of Victorville, just beyond a granite spur that projects toward the road from a group of mountains to the north. Near the north edge of this dry lake miners are reported to have drilled a 300-foot well, in which the water rises within 150 feet of the surface. The well is not on the road and can not be seen from it, but a dim trail goes northward across the dry lake to it. The next water is at the Box S Ranch, about 6 miles southeast of this point.

188. *Rabbit Springs, San Bernardino County (M-5).*—Rabbit Springs (elevation about 2,900 feet) have for years been a favorite camping place for parties traveling eastward from Victorville along the north flank of the San Bernardino Range. The springs are about 2 miles north of Box S ranch, on the northwest edge of Rabbit Dry Lake, and are marked by a clump of cottonwood trees that can be seen from the low divide 3 miles west. Since artesian water was found at Box S ranch, travelers have generally followed the road that passes it. At the east edge of the dry lake just west of Box S ranch a road turns to the left (northward) from the main road and crosses a saddle in a rocky point just ahead, while the main road passes south of this point. This left-hand road leads to Rabbit Springs. Some freight teams follow it as the distance is a little less to Copper Well (No. 195), Old Woman Springs (No. 196), and Mean's Well (No. 198) than by way of Box S ranch.

The waters of Rabbit Springs are presumably artesian, and derived from the same source as are those of the Box S wells. The supply is sufficient to irrigate a section or more of land.

189. *Box S ranch, San Bernardino County (M-5).*—Box S ranch (Pl. IV, B), elevation 2,935 feet according to U. S. Geological Survey), should not be confused with Box S Springs (No. 192), which are about 6 miles southeast of the ranch. The ranch receives its name from the cattle brand of the company that owns it, the brand being a square inclosing the letter S. The ranch is about 24 miles east of

Victorville, on the county road that leads to the mines in the San Bernardino Mountains, and eastward into the desert. Several wells have recently been drilled at the ranch and in its vicinity, some of which yield flowing water, so that an abundant supply is now available. The locality is easily recognized because of the ranch buildings, the first to be seen by the traveler after he leaves Mohave River at Victorville. It is an important point for desert travelers, because the water is the first to be had along this road east of the river. Meals also may be obtained here.

190. *Spring (no name), San Bernardino County (M-5).*—This is a small spring along the north face of the San Bernardino Mountains, almost due south of Dead Man's Point. It supplies miners who are developing copper prospects in the vicinity. Their tent houses may be seen to the south from the county road that extends from Victorville east.

191. *Lucerne Valley Well, San Bernardino County (M-5).*—In the winter of 1905-6 a well was drilled at the Lucerne Valley ranch, which is about one-half mile north of the wagon road from Rabbit Springs to Old Woman Springs (No. 196). The site, like that of Box S ranch, is marked by buildings.

192. *Box S Springs, San Bernardino County (M-5).*—These springs issue at the base of a low alkaline terrace just north of the road that leads from the Box S ranch southeastward to the Rose mine, in the San Bernardino Mountains. A trough stands by the roadside, and the water is conducted to it by an iron pipe. There is a small but constant flow, and the water is sufficiently free from salts for all purposes. Cushenbury Springs (No. 193) are only about 3 miles distant to the southeast, and the Box S ranch is about 6 miles northwest.

193. *Cushenbury Springs, San Bernardino County (M-5).*—Cushenbury Springs are on the county road that runs from Victorville to Gold Mountain, Doble, Holcomb Valley, and the Rose mine, which are all in the San Bernardino Mountains near Bear Lake. The springs are at the base of the San Bernardino Range near the mouth of a canyon at an elevation of 4,042 feet (U. S. Geological Survey) and are 9 or 10 miles southeast of Box S ranch and about 3 miles beyond Box S Springs. They are marked by a clump of tall cottonwood trees, with alfalfa fields to the south and east and a dwelling among the cottonwoods. There is a good corral and a watering trough by the roadside, to which the water is piped. The yield of the springs is from 3 to 4 miner's inches.

194. *Cactus Flat Springs, San Bernardino County (M-5).*—Cactus Flat Springs (elevation about 5,900 feet) are near the northern crest of the San Bernardino Mountains on the fruit ranch of Mr. J. C. Johnson, who has lived here many years and is the postmaster of Cactus Flat. The ranch and springs are about 6 miles southeast of Cush-

enbury Springs, on the county road from Victorville to Gold Mountain, Holcomb Valley, and the Rose mine. The place is very readily found, as the road, which is well graded and well traveled, runs near the orchard, the house, and the corrals. Troughs are built by the side of the road for watering horses. The springs yield sufficient water to irrigate a number of acres of fruit land. A small stock of canned goods and other supplies is kept by the postmaster, so that travelers may replenish a depleted larder here.

195. *Copper Well, San Bernardino County (M-5).*—This is a new well, recently sunk by miners who are at work on some gold and copper prospects at the east end of Lucerne Valley. It is on the road from Box S ranch to Old Woman Springs (No. 196) and is marked by the miners' buildings.

196. *Old Woman Springs, San Bernardino County (M-6).*—These large springs are at the north base of the San Bernardino Mountains, about 12 miles east of Box S Springs, on the north road from Victorville to Dale, at an elevation of 3,186 feet (U. S. Geological Survey). They should not be confused with the other Old Woman Springs (No. 183) about 90 miles farther east. The water is somewhat alkaline, like that at Box S Springs. The site is marked by a group of cottonwood trees, a ranch house, an orchard, and an alfalfa field. The springs are said to yield from 8 to 30 miner's inches, varying with the season. Hay may be purchased and other accommodations may be had at the ranch at these springs.

197. *Rock Corral, San Bernardino County (M-6).*—A well-known spring, marked by an old rock corral, is situated at the north edge of the San Bernardino Range, about 9 miles west of south from Mean's Well (No. 198), at an elevation of 3,600 feet. The water is abundant and good.

198. *Mean's Well, San Bernardino County (M-6).*—The Gold Pin Mining Company has dug a well 26 feet deep at the northwest edge of Mean's Dry Lake. The water rises within 12 feet of the surface. The company has installed a 12-horsepower gasoline engine to pump the water to its mine, which is in the mountains directly north of the lake. The next water on the west is at Old Woman Springs, about 12 miles distant, but there is another well (No. 199) about 6 miles southeast of Mean's Well on the road to Dale.

199. *Wilbur Well, San Bernardino County (M-6).*—This well is about 6 miles southeast of Mean's Well and about 16 miles west of Surprise Spring (No. 200) on the country road from Victorville by way of Mean's Well to Dale. The water is of good quality, and the well is easily found, as it is close by the roadside.

200. *Surprise Spring, San Bernardino County (M-7).*—This spring is on the county road from Victorville to Dale by way of Mean's Well, about 6 miles west of Mesquite Dry Lake, about 16 miles east of

Mean's Well, and about 12 miles north of Mesquite Spring (No. 211). The spring receives its name from the fact that it is in the open desert where one would least expect to find water. It is close to the roadside, and the location is clearly marked by camp debris. The water is of fair quality.

201. *Dead Man's Hole*, San Bernardino County (M-7).—The springs known under this name are on the west side of Mesquite Dry Lake and east of the county road. They are little more than mud holes in the playa deposits around the lake. The water is full of magnesia and soda salts and is very laxative, but can be used by animals.

202. *Spring (no name)*, San Bernardino County (M-8).—This is a spring at the northeast side of the Bullion Mountains, near some old mine workings about 4 miles west of Bristol Lake and about 8 miles southwest of Bagdad station, on the Santa Fe Railway. A trail leads from the station to the spring, which is used only by local prospectors.

203. *Spring (no name)*, San Bernardino County (M-10).—This spring is on the west side of Old Woman Mountain, on an old road that runs from Dale northward to a point about 9 miles south of Cadiz, where it turns eastward and crosses the road from Danby station to Danby Lake. It is the first road crossed in driving south from the railway at Danby. The spring is about 6 miles east of the Danby road, in the main canyon of the mountain, and is marked by the ruins of a mining camp. A mill stood near the spring at one time. The supply of water is not large, but the quality is excellent.

204. *Springs (no name)*, San Bernardino County (M-10).—These are small springs in the southern end of Old Woman Mountain, about 6 miles north of Danby Lake and about 3 miles east of the road from Danby station to the lake. This road crosses a dry wash containing cottonwood trees, and the springs are found by following this wash into the mountains. They are not on a main road and are not particularly well known, but are used by prospectors. The water flows from granite and is of good quality.

205. *West Well (new)*, San Bernardino County (M-13).—This well is on the county road from Needles, Cal., to Parker, Ariz., and is about 30 miles south of Needles, 4 miles southwest of the old West Well (No. 206), and 25 miles northwest of Parker. It is close by the roadside, is protected by curbing, and is provided with a pump and a covered watering trough. The supply of water is sufficient for all needs.

206. *West Well (old)*, San Bernardino County (M-13).—This well is near the head of the Chemehuevis Wash, on the county road that runs from Needles, Cal., to Parker, Ariz. It is about 40 feet deep and stands in a clump of cottonwood trees. It is protected by curbing and

provided with an iron pump and a good watering trough with cover. The water rises within about 6 feet of the surface and is of excellent quality.

Since this well was dug the county road has been straightened. The main road now diverges from the old road about 3 miles west of this well and continues southward into the next township, where a new well has been dug. The old well is convenient for prospecting parties in the Chemehuevis Wash.

207. *Warren's ranch, San Bernardino County (N-6).*—This well-known ranch is 28 miles northeast of Banning, at the highest point along the road from Banning to Dale, its elevation being 2,500 feet. It is the usual stopping place for all travelers bound from the north end of the Colorado Desert or from San Gorgonio Pass northeastward by way of Morongo Pass. It is a road ranch and provides travelers with meals, hay, grain, and other supplies. The water used flows from large springs and is pumped to the ranch by a gasoline engine.

208. *Warren's Well, San Bernardino County (N-6).*—This well is 10 or 12 miles east of Warren's ranch. It is 150 feet deep, and the water is pumped by a windmill into a cemented reservoir about 18 feet long, 10 feet wide, and 4 feet deep. Fifteen cents is charged for each team watered here. It is 27 miles by road from the well to Twenty-nine Palms Springs (No. 213).

209. *Coyote Holes, San Bernardino County (N-7).*—This watering place, originally of some importance but now fallen into disuse, is about 7 miles east of Morongo Pass, at the junction of the wagon roads from Victorville, on the Santa Fe, and Banning, on the Southern Pacific. It is about 18 miles by road from Coyote Holes eastward to Twenty-nine Palms Springs and about 9 miles west to Warren's Well. Warren's Well and the springs at Warren's ranch now supply travelers with water, so that Coyote Holes are no longer used and have become badly choked with sand. A slight seepage, however, may be found in a canyon about 1 mile south of the road junction.

210. *Quail Springs, San Bernardino County (N-7).*—These springs are at the north edge of the San Bernardino Range, about 6 miles southeast of Coyote Holes. The water is excellent and the supply can no doubt be increased.

211. *Mesquite Spring, San Bernardino County (N-7).*—Mesquite Spring is on the road from Victorville to Dale by way of Mean's Well, about 3 miles south of Mesquite Dry Lake and 7 miles northwest of Twenty-nine Palms Dry Lake. Its site is marked by granite outcrops, a mesquite grove, and the débris of old camps. The water is of good quality and the supply is ample for travelers.

212. *Sulphur Springs, San Bernardino County (N-8).*—These springs are about 2 miles south of Mesquite Springs, on the county

road from Victorville to Dale. The water is abundant, but tasteless and strongly of sulphur; and as it is but a few miles southward to the better springs these are rarely used by travelers.

213. *Twenty-nine Palms Springs, San Bernardino County* (N-8).—The Twenty-nine Palms Springs are scattered for a distance of a mile along the southwest edge of Twenty-nine Palms Dry Lake, about 6 miles south of the south end of the Bullion Mountains, on the road from Victorville and Banning to Dale and 27 miles east of Warner's Well. They receive their name from the clumps of native palm growing about them. An adobe building stands near the camp place. The water at the springs is abundant enough to supply a number of mining camps in the vicinity. There are several shallow wells near the springs, from which water may also be procured.

214. *Dale Pump, San Bernardino County* (N-9).—A pump plant has recently been installed at the south edge of Dale Dry Lake in T. 1 N., R. 12 E., the well, however, being just over the town line to the south. This plant supplies water to Dale, a mining settlement about 5 miles farther south. Dale, long known as Virgin Dale, is the post-office and trading center for the prospectors in the mountains around it. The location of this settlement has been changed several times during the last ten years, but with the development of water its present position will probably prove permanent. The well is reported to furnish an abundant supply of water of good quality.

215. *Desert Well, San Bernardino County* (N-11).—This well is reported to have been drilled near the southeast edge of Iron Mountain, about 4 miles southwest of Miller's Well (No. 216). The well was searched for it recently, but was unable to find it, although it is supposed to be in the SW. 1/4 sec. 3, T. 1 S., R. 18 E., San Bernardino meridian. From the abundance of water plants, however, it is evident that water can be procured without much difficulty in that vicinity.

216. *Miller's Well, San Bernardino County* (N-11).—Miller's Well is situated on the southwest edge of Danby Dry Lake, among gypsum knobs at the east base of Iron Mountain. It is beside a road that runs southeastward from Danby station, on the Santa Fe Railway, to the Maria Mountains. The well is about 3.5 miles south-southeast of Danby. Brown's Well (No. 232) is 20 miles southeast. The water is dark colored and very salty, and only the animals will drink it. Travelers, therefore, should carry with them from Danby an ample supply for men and teams. It is reported that there is another well on the southwest side of Iron Mountain, but the writer was unable to find it. There are two other Miller wells (Nos. 299 and 301) in Nevada, but this well is not likely to be confused with them.

217. *Spring, San Bernardino County (N-12).*—There is a spring near the southeast end of the Turtle Mountains, about 15 miles northeast of Brown's Well (No. 232) on the road to the West Well (No. 205). The water is good.

218. *Palm Springs station, Riverside County (O-6).*—Palm Springs is a station on the Southern Pacific Railroad in the upper end of the Colorado Desert. It is supplied with water from wells. This station should not be confused with Palm Springs proper, which lies at the base of San Jacinto Peak, 6 miles due south. (See No. 219.)

219. *Palm Springs, Riverside County (O-6).*—This is an agricultural settlement and health resort in the upper end of the Coachella Valley, about 6 miles south of Palm Springs station on the Southern Pacific Railroad, at an elevation of 455 feet (U. S. Geological Survey). The lands of the settlement are irrigated in part from these rather large springs, and in part from Whitewater River and the near-by canyons of the San Jacinto Mountains. There are a number of springs here, and some of them are thermal and medicinal. The settlement is named from the wild palms which grow in the vicinity. It is one of the most northerly points in the United States at which these plants are found native.

220. *Palmdale, Riverside County (O-6).*—This agricultural settlement, now largely abandoned, is about $2\frac{1}{2}$ miles southeast of Palm Springs, at an elevation of about 450 feet. Its irrigation was accomplished by utilizing a group of springs that give a good supply of water.

221. *Magnesia Spring, Riverside County (O-6).*—This is a spring of effervescing magnesia water in Magnesia Spring Canyon, about 15 miles west of Indio. The mouth of the canyon is about 2 miles southwest of the Indio road, which passes along the south side of Coachella Valley. A dim trail turns to the southwest from this main road at a point about 6 miles west of Indian Well (No. 234) and leads up to the spring.

222. *Stubby Springs, Riverside County (O-7).*—These springs are on a trail from Palm Springs station to what is known locally as the Thousand Palms Canyon. This canyon is at the southwest edge of the San Bernardino Range, about 18 miles north of Indio. The springs were opened by a freighter known locally by the nickname "Stubby," who made the trail into the canyon.

223. *Lost Horse Spring, Riverside County (O-7).*—This is a spring near the summit of the San Bernardino Mountains, about 6 miles east of the Thousand Palms Canyon. A pack trail leads to it. The spring takes its name from a mining company that at one time operated a 2-stamp mill there, using the water from the spring for the purpose.

224. *Piñon Pine Well, Riverside County (O-8).*—This well is about 25 miles northeast of Indio, on the new wagon road to Twenty-nine Palms Springs. The air-line distance is perhaps 15 miles. A mining company has erected a 2-stamp mill here and sunk a well from which a good supply of pure water is derived. The well receives its name from the piñon trees around it.

About 3 miles southeast of this camp, away from the main road or trails, are the Red Tanks, where water collects in a bowl in the granite. The writer has no information as to the permanency of this supply or the quality of the water.

225. *Stirrup Tanks, Riverside County (O-8).*—These tanks or natural rock basins are in the granite of an unnamed range, the one next west of Pinto Mountain. They are on the road from Indio to Twenty-nine Palms Springs, and have not been known to be dry during the last ten years, a period of exceptionally low rainfall in the Southwest. The water is of excellent quality. Travelers may learn the route to them at Indio or Twenty-nine Palms Springs.

226. *Washington Tank, Riverside County (O-8).*—This tank is in the San Bernardino Range, about 16 miles west of Cottonwood Springs (No. 227). The water is said to be of excellent quality and a fair supply may be depended on in ordinary seasons. Travelers will have to make local inquiries in order to find the tank.

227. *Cottonwood Springs, Riverside County (O-9).*—These springs are in Cottonwood Pass, 26 miles northeast from Mecca, on the main road to Dale. They are 14 miles northeast of Shaver Well (No. 241). The springs are readily found, their site being marked by the ruins of a concrete reservoir and by the corral, water troughs, and engine house of the Iron Chief Mining Company. The water, which is of good quality, is usually flowing, but more or less débris often obscures or obstructs the springs during the winter rains, so that the first travelers in the early spring are obliged to clean them out. About 3½ miles east, on a trail on the south slope of Cottonwood Mountains, are many large native palms growing in the canyons, where water is always standing exposed or close to the surface. At the southwest end of the Providence Range, 75 miles northward, are other springs of the same name (No. 162).

228. *Iron Chief Well, Riverside County (O-9).*—This well is in the northeast end of Eagle Mountains. It is reached by a side road from Cottonwood Springs, which lies about 8 miles southwest. The water is good.

229. *Lightfoot or Boulder Well, Riverside County (O-10).*—About 6 miles west of Palen Dry Lake a well has been sunk by Lightfoot Brothers, who have erected over it a windmill which is visible for a number of miles. This windmill and pump are usually out of order.

230. *Palen Wells, Riverside County (O-10).*—There are two old wells, 14 feet deep, at the southwest edge of Palen Dry Lake, a few miles east of the Lightfoot well. The water is brackish but potable. In 1905 it was reported that Mr. H. R. Adams drilled a new well near the old ones.

231. *Packard Well, Riverside County (O-11).*—The Packard Well is about 21 miles northeast of the Lightfoot Well, in the Palen Mountains. It is near the bottom of a small arroyo and is surrounded by mesquite trees. The well is not covered, so that the water is often contaminated by the bodies of desert animals. A ridge of limestone south of the well serves as a landmark.

232. *Brown's Well, Riverside County (O-11).*—This is a drilled well, 300 feet deep, near the junction of the roads from Mecca and from Danby Lake to Ehrenberg, Ariz. Its location is plainly determinable from the road, as there are two adobe buildings and a corral near it. It is owned by Floyd Brown, who lives there. No charge is made for water.

234. *Indian Well, Riverside County (P-7).*—This well is situated among the sand hills about 6 miles west of Indio, at an elevation of 97 feet (U. S. Geological Survey). It is on the road along the southwest side of the Coachella Valley, connecting Palm Springs with the settlements about Indio, and is just north of a rough spur of the Santa Rosa Range that extends northwestward for some miles into the desert. The well is 30 or 40 feet deep and is an open shaft in which a pump has been placed.

235. *Indio, Riverside County (P-7).*—Indio (15 feet below sea level), the end of a division on the Southern Pacific Railroad, is well known as a health resort and as the shipping point for a thriving agricultural district. The railroad company has wells here and a pumping plant for supplying the settlement and the road. In this vicinity there are also many other pumping plants that supply water of the finest quality in considerable volume for irrigation and other purposes.

236. *Coachella pumping plant, Riverside County (P-7).*—The Southern Pacific Railroad Company has installed a pumping plant at Coachella station, which is between Indio and Mecca. The water comes from the deep gravels that underlie the Coachella Valley. Throughout this valley from Indio to Mecca there has been rapid development since 1900 by the utilization of underground waters. There are now several hundred wells bored, most of them yielding artesian water of the finest quality. Their use is rapidly transforming this part of the desert into a rich agricultural district.

237. *Toro Springs, Riverside County (P-7).*—This group of springs and the one next to be described are two among a number of ciénagas in which the artesian waters under this part of the desert rise to the

surface. Indian settlements are grouped about these watering places, which were formerly of much importance, but are now less valuable because of the numerous artesian wells in the vicinity. Toro is about 9 miles south of Indio, at 111 feet below sea level, on the old wagon road that follows the western edge of the Colorado Desert.

238. *Alamo Bonito Springs, Riverside County (P-7).*—These springs, which are similar to those at Toro, just described, are about 5 miles southwest of Mecca, at 186 feet below sea level (U. S. Geological Survey). The name is Spanish, and signifies "good poplar." Cottonwood trees are abundant in this vicinity.

239. *Agua Dulce, Riverside County (P-8).*—This is a cluster of strong springs of "sweet water," as the Spanish name indicates, on the west side of the Colorado Desert, about 7 miles south of Mecca, on the road from Mecca to Seventeen Palms Springs (No. 234). They lie 183 feet below sea level (U. S. Geological Survey). The springs are due to the up-welling of artesian waters that are imperfectly confined by the clay strata underlying this part of the Colorado Desert. There are a number of springs in the group, and several Indian habitations are scattered around them. The flow is constant, so that water may be obtained here at any time. Originally they were of much importance, but the settlement of this particular region and the boring of artesian wells in the vicinity have lessened the value of the natural springs.

240. *Mecca, Riverside County (P-8).*—Two artesian wells bored at Mecca station by the Southern Pacific Railroad Company were among the first successful wells in the Coachella Valley. They have a strong flow, and besides furnishing a supply for the locomotives and tank cars of the Southern Pacific system, are utilized by some of the settlers in the village.

241. *Shaver Well, Riverside County (P-8).*—This well is about 12 miles northeast of Mecca, on the road to Dale. It is at the upper end of a box canyon, within sight of the road, and is easily found. It is about 30 feet deep, well timbered and protected. There is a rope, bucket, and pulley, so that it is easy to get the water, which is of superior quality. The well is surrounded by mesquite shrubs and palo verde. Three miles southwest of Shaver Well, in a canyon that opens to the south, over a ridge, half a mile south of the county road, is water surrounded by a few burnt palms, and about 2 miles farther to the southeast, up another canyon in a little side glen, is a beautiful clump of palms with a spring of pure water beneath them.

242. *Dos Palmas, Riverside County (P-8).*—Dos Palmas is a well-known stopping place on the old San Bernardino and Yuma road, about 6 miles east of new Salton station, on the Southern Pacific Railroad, near the clearly defined old beach line that stands 40 feet above sea level in the Colorado Desert. The position of the springs

is marked by two large desert palms, which give the name to the place. The springs yield a large quantity of tepid and slightly salty but drinkable water, the first to be found on this old road southeast of Mecca, which is about 16 miles distant. The next water to the southeast is at Frinks Springs (No. 258), 12 miles away. Since the building of the Southern Pacific Railroad the old wagon road is only occasionally used.

The Orocopia Mining Company has established a pumping plant at the springs, by means of which the water is pumped to its mines, 12 miles farther north.

243. *Canyon Springs, Riverside County (P-9).*—These springs, which yield a small supply of poor water, are in a side canyon north of the road that runs from Mecca via Salton to Palen Dry Lake. South of the springs the road branches, one fork crossing the pass in the Chuckwalla Mountains to the north and the other fork turning southeastward across the divide to the Ironwood Mountains. Water is again found on the northern road, near the southwest edge of Palen Dry Lake, about 25 miles away.

244. *Mill Camp, Riverside County (P-10).*—This is a mining camp about 30 miles east of Salton, on the Ehrenberg road. There are buildings at the springs, which furnish plenty of good water.

245. *Aztec Well, Riverside County (P-10).*—This well is about 9 miles east of Mill Camp on the road to Ehrenberg. There is an abundance of good water.

246. *Granite Tanks, Riverside County (P-10).*—These tanks or natural basins in the granite are at the northeastern edge of the Chuckwalla Mountains. The water, which is of fine quality, rises at the foot of a granite outcrop in a little *ciénaga* about 25 feet across, and flows over the surface for a short distance before it sinks into the sand. More water could probably be procured here by development. The tanks are on the road from Mecca station to the Ironwood Mountains, about 6 miles southwest of Long Tanks, another watering place of similar character, and about 10 miles south of the Palen Wells (No. 230). Lightfoot or Boulder Well (No. 229) is about 14 miles northward by road. The first water to be obtained to the east is at McCoy Spring (No. 249), in the Ironwood Mountains, 25 miles distant.

247. *Corn Springs, Riverside County (P-10).*—These springs are situated on the east side of the Chuckwalla Mountains, about 6 miles south of Granite Tanks. The water, which amounts to 8 or 10 miner's inches, rises in a local *ciénaga*. It is probable that careful development would increase the flow and furnish water enough for the irrigation of a number of acres.

248. *Chuckwalla Spring, Riverside County (P-10).*—This spring is on the south road from Mecca to Palo Verde, near the southwest edge of the Chuckwalla Mountains, in a pass that separates this range and the Chocolate Mountains. The water is of excellent quality and is fairly abundant.

249. *McCoy Spring, Riverside County (P-11).*—This spring is on the west edge of the McCoy or Ironwood Mountains, about 25 miles east of Granite Tanks, on the road from Mecca to Ehrenberg. The water is excellent, but the supply is small, the springs yielding only about 4 barrels a day.

250. *Springs (no name), Riverside County (P-12).*—These springs are at the east edge and near the north end of the Palo Verde Mountains, about 7 miles northwest of the town of Palo Verde, and are used by stockmen.

251. *Spring (no name), Riverside County (P-12).*—There is reported to be a good spring on the old Ehrenberg road to Mecca, about 5 miles northwest of Colorado River, but the writer has no further information concerning it.

252. *Borego Spring, San Diego County (Q-7).*—Borego Spring is on the west bank of the broad Borego Wash, at an elevation of 452 feet (U. S. Geological Survey). Its distance by wagon road from Julian is about 33 miles. The water of this spring, although somewhat alkaline, is entirely usable. Mesquite trees grow near the spring and in the valley, and salt grass, willow, and rushes are abundant. An old cabin stands on the bank about 50 feet from the spring and serves to mark its position.

From Borego Spring the wagon road runs down the Borego Wash about $2\frac{1}{2}$ miles to its junction with the San Felipe Wash, which comes in from the southwest. Just beyond the junction of the two washes the road forks, one branch continuing down the San Felipe, the other turning to the left and crossing the mesa and the clay hills toward Seventeen Palms Springs (No. 254). Neither road is much used, and after rains both are dim and difficult to follow.

253. *Clark Well, San Diego County (Q-7).*—This well is about three-fourths of a mile north of the northeast end of Clark Dry Lake, at an elevation of 555 feet (U. S. Geological Survey). Trails lead to it from Rock House Canyon and from Coyote Creek valley, and a little-used wagon road connects near Borego Spring with the road from Seventeen Palms Springs to Julian. The well can be easily found from its position north of the dry lake. The water is good.

254. *Seventeen Palms Springs, San Diego County (Q-7).*—Seventeen Palms Springs lie at an elevation of 410 feet (U. S. Geological Survey), near the junction of three washes in the clay hills, south of the Santa Rosa Mountains. At present only eight or nine palm trees stand near them, the remainder of the seventeen, from which the

springs were named, having been destroyed by fire. The springs are about 12 miles by wagon road east from Borego Spring, or 45 miles from Julian, but the road is little used, is dim, and may be difficult to follow, particularly after the winter rains. Broken clay hills and deep washes surround the springs. Grass and wood in small quantities may be found near them. When they are kept open the water is fairly good, but it becomes bitter and bad by neglect and disuse. The soil is impregnated with alkaline salts.

255. *Soda Springs, Imperial County* (Q-8).—Soda Springs are located about 15 miles southeast of Fish Springs (No. 256), on the road from Mecca down the west side of the Colorado Desert. The water is so salty as to be scarcely potable and near by are other springs whose water is entirely undrinkable. Soda Springs are at the base of a low barren knoll, one-half or three-fourths of a mile south of Clay Point, marked by a government bench mark, around which the road turns on the way from Mecca to Seventeen Palms Springs. The road from Clay Point south toward Harper Well (No. 264) is very little traveled and is difficult to find.

256. *Fish Springs, Imperial County* (Q-8).—Fish Springs (230 feet below sea level), now (1908) submerged to a depth of about 25 feet beneath Salton sea, are a group of strong natural springs whose aggregate yield is several miner's inches. The waters are tepid and slightly saline, but of sufficiently good quality to be used by men or animals without injurious effects. Before their submergence these springs were especially important to travelers because they are at the southernmost point at which water of fair quality can be procured in abundance along the west side of the desert until Harper (Mesquite) Well is reached. They will emerge again as the lake shrinks by evaporation, and when the lake water has become too saline for use they will again become important. Their position is indicated by a prominent rocky point which stands out in the desert about 1 mile east of the base of the Santa Rosa Mountains, and which is conspicuous not only because of its position but because of the distinct water line that encircles it 10 or 15 feet below its summit. This point is about 2 miles northeast of the springs.

257. *Figtree John's Springs, Riverside County* (Q-8).—This small group of springs is about 12 miles south of Mecca station, and about 3 miles southeast of Agua Dulce, at 197 feet below sea level (U. S. Geological Survey). About the springs are clustered the huts of the family of Figtree John, one of the Coahuila Indians. The water is tepid but is abundant and of excellent quality. The position of the springs is marked by a number of large fig trees. They are about 1 mile east of north of a rocky outlier of the Santa Rosa Mountains, which also serves as a landmark for the location of Fish Springs, about 3 miles farther south. Figtree John's Springs

were submerged during the winter of 1906-7 by the rising waters of Salton Sea, but will reappear as the water subsides.

258. *Frinks Springs, Imperial County* (Q-9).—These springs are about 6 miles northwest of Frinks station, on the Southern Pacific Railroad. They are on one of the old wagon roads from San Bernardino to Yuma, near the old beach line that stands about 40 feet above sea level in the Colorado Desert. The water is of good quality and in fair quantity.

259. *Spring (no name), Riverside County* (Q-11).—This spring is at the south base of a western outlier of the Palo Verde Mountains, about 6 miles northeast of the Chuckwalla settlement, on the road thence to Ehrenberg, Ariz. The spring is near the road, has long been known and used, and is readily found. The quality of the water is good and the supply is fair.

260. *Mule Springs, Riverside County* (Q-11).—These springs are in the main pass on the west side of the Palo Verde Mountains, on the road from Mecca to Palo Verde, by way of Chuckwalla, and about 8 miles northeast of the Chuckwalla settlement, which itself lies at the east base of the Chuckwalla Mountains. The position of the springs is marked by a grove of timber. The water is good and the supply abundant.

261. *Vallecito Springs, San Diego County* (S-7).—Vallecito Springs are located in the valley of Vallecito Creek, about 33 miles east of Julian, on the wagon road to Carrizo station (No. 270), at an elevation of about 1,600 feet. The old adobe stage station, in use when this road was a part of one of the transcontinental stage routes, still stands and is in fairly good condition. A watering trough stands near the building, and there are mesquite and cottonwood trees in the vicinity. The quality of the water is fair.

262. *Hanna Well, San Diego County* (R-7).—This well is at the base of the north slope of Black or Fish Creek Mountain, 15 or 18 miles southeast of Borego Spring, and 10 or 12 miles southwest of Harper (or Mesquite) Well (No. 264). It is not on a main road, but is near the mouth of a canyon heading in a pass that leads to the valley of Carrizo Creek. The water is good.

263. *McCain Springs, Imperial County* (R-8).—McCain Springs are about 5 miles somewhat east of south of Clay Point, mentioned in the description of Soda Springs (No. 255). They are in the center of a broad wash, locally called the Arroyo Grande, and are marked by three large sand dunes from a quarter to half a mile southwest. The surrounding country is traversed by numerous gulches from 6 to 20 feet in depth and often difficult to cross. The springs, which are well below sea level, have built up a small mound in the bed of the wash. The water appears to be charged with carbonic acid gas and is fairly palatable.

In March, 1901, excellent water was found by digging a hole in the sand near the right bank of the wash, about 430 feet upstream from the springs. Firewood is scarce in the vicinity, but grass for stock may be found some distance away. These springs are about 9 miles southeast from Seventeen Palms Springs.

264. *Harper (or Mesquite) Well, Imperial County (R-8).*—At the junction of Carrizo and San Felipe creeks an attempt was made a few years ago to develop oil. No oil was found, but at a depth of about 300 feet a flow of good water was obtained. The site of the well is plainly marked by the derrick, which can be seen for a long distance across the desert. There is an abundance of mesquite timber in the vicinity.

265. *Kane Spring, Imperial County (R-8).*—This spring is 6 miles east of Harper Well, on top of a low knoll. It is surrounded by cane, salt grass, and arrow weed. The water is full of soda and is very poor, being hardly fit for use.

266. *Agua Caliente Springs, San Diego County (S-7).*—About 3½ miles eastward from Vallecito Springs and about three-fourths of a mile southeast of the main wagon road between Julian and Carrizo station there are several springs in a natural amphitheater comprising an area of about 50 acres. The water is tepid and is impregnated with sulphur, but is not unpleasant to the taste. The combined flow of the springs makes a rather large stream. Grass and wood are scarce.

267. *Mountain Palm Springs, San Diego County (S-7).*—These springs are at the foot of a high, broken rocky ridge and are several miles south of the main wagon road across the Sierra Madre, but can be easily reached by a side road that was made a few years ago. The water is cool and fairly good. Wild palms and other vegetation make the vicinity inviting.

268. *Palm Springs, San Diego County (S-7).*—There are several Palm Springs in San Diego County, but those here referred to are about 9 miles east of Vallecito Springs, just north of the line between sections 25 and 36. The palms that gave the springs their name were destroyed long ago, but there are several mesquite trees near by. The springs are situated under a clay bank, and digging is sometimes necessary in order to obtain water. The water has a temperature of about 60° and is somewhat sulphurous.

269. *Mason ranch, San Diego County (S-7).*—Mason ranch is on the road from Carrizo Creek to Sentenac and Agua Caliente (Warner's ranch). This is the principal road through this part of the desert, and may be easily followed and identified. At the ranch, which will be recognized at once by travelers over the road, an excellent supply of water has been developed.

270. *Carrizo station, San Diego County (S-8).*—Carrizo station (elevation, 450 feet) is near the left bank of Carrizo Creek wash about 9 miles east of Palm Springs, on the main wagon road from Julian to the Imperial Valley. There are a number of springs near the station, and two of them furnish fairly good water. There is also a rather large tule swamp around the station, from which a strong stream of alkaline water flows. Rough clay hills of late Tertiary age, showing typical badland erosional forms, are prominent features of this region. Carrizo was originally a stage station on one of the old overland lines, but the adobe buildings are now in a dilapidated condition, their ruin having been completed by the earthquake of February, 1892.

271. *Coyote Well, Imperial County (S-8).*—Coyote well is about 375 feet above sea level, on the main wagon road from Mountain Springs (No. 274) to Silsbee, the southernmost of the wagon roads that cross the Sierra Madre from the Imperial Valley to San Diego. The old Coyote well was a mere pit curbed up with planks. A new well, standing about 100 feet from the old one, was fitted up with a pump, but this has been broken recently. The water is rather alkaline, but improves after the well has been used for some time.

272. *Yuha Springs, Imperial County (T-8).*—Yuha Springs are located in a wash near the corner of sections 5, 6, 7, and 8, about 5 miles southeast of Coyote well and a mile southwest of the derrick at the Yuha oil well. The regular wagon road from Campo to Silsbee crosses the desert about 2 miles north of the springs. The water is impregnated with alkaline matter, but when used continuously is not unpleasant or harmful. In 1905 there was a trough and pump at the springs.

273. *Sunset Springs, Imperial County (S-10).*—These springs, which have long been known, are about 13 miles south of east from Brawley, below the old beach which is so prominent a feature about the borders of the Colorado Desert. It is reported that the paths of animals using the springs led to their discovery. They are of less importance now than before the reclamation of so large a part of the Imperial Valley by the introduction of Colorado River waters.

274. *Mountain Springs, San Diego County (T-7).*—Mountain Springs are about 9 miles by wagon road from Jacumba Springs (No. 275) and 33 miles from Campo, at an elevation of about 2,500 feet. Forty years ago there was a stage station here on the Butterfield stage line that ran from San Diego to Yuma. The ruins of the old stone corral and buildings are still visible. The water issues from the side of a rocky ravine and a portion of it is carried in an inch pipe about 200 feet long to a trough beside the road. Its quality is excellent.

From Mountain Springs the wagon road leading to the desert runs through a rocky gorge in which water can be found a portion of the year. From the mouth of the gorge the surface slopes gently eastward to Coyote Well, 12 miles from Mountain Springs and 45 miles from Campo.

275. *Jacumba Springs, San Diego County (T-7).*—Jacumba Springs are about 24 miles east of Campo, near the quarter-section corner between sections 7 and 8, T. 18 S., R. 8 E., and about $\frac{1}{4}$ mile north of Monument No. 233 of the boundary line between the United States and Mexico, at an elevation of about 2,825 feet. They are on the west side of a long, open valley whose outlet is to the northeast, through a deep, narrow gorge. The greater part of this valley, which is the head of the Carrizo Creek drainage system, is in Mexico. The springs include one of cold water and several that yield waters with temperatures ranging from 86° to 98° F. These thermal waters are regarded as medicinal, and a bath house and other accommodations are provided for travelers.

NEVADA.

276. *Palmetto, Esmeralda County (A-3).*—This is one of the oldest settlements in the northern portion of the Palmetto Range, and is an outfitting point for prospectors in that region. It is reached by a road from Alvord station, on the Southern Pacific Railroad, by way of Deep Springs and Oasis, and is well supplied with water from both wells and springs.

277. *Indian Spring, Esmeralda County (A-3).*—This spring is about 6 miles east of the Palmetto Mountains and about the same distance northwest of Barrel Springs (No. 278). Parties prospecting in the region can obtain full directions for reaching it at Palmetto or at Lida.

278. *Barrel Springs, Esmeralda County (A-3).*—These springs are in the eastern edge of the Palmetto Mountains, about 1 mile northeast of Lida and about 5 miles southeast of Indian Spring. As the country is comparatively well settled, directions for finding the springs can be had at Lida or at Palmetto.

279. *Gold Mountain, Esmeralda County (A-4).*—There is a well at this point, 1 mile east of Tokop and 20 miles southeast of Lida, that yields a small supply of good water. There is another well $1\frac{1}{4}$ miles northeast of this one, across two small ridges. The water is good.

280. *Old Camp, Esmeralda County (B-4).*—This is a small spring near the summit of Gold Mountain, having a fair supply of good water.

281. *Willow Spring, Esmeralda County (B-4).*—This is a small spring on the east side of Gold Mountain, near the summit, $1\frac{1}{2}$ miles southeast of Old Camp. The supply is scanty, but the water is good. There is also a spring of the same name (No. 287) about 20 miles southeast, in the Grapevine Range.

282. *Thorp Mill, Nye County (B-5).*—This site is marked by an old stamp mill. It was originally a stage station and post-office on the road from Goldfield to Bullfrog, but the station has been abandoned and the post-office moved to Bonnie Claire station, $2\frac{1}{2}$ miles farther north. The road between Goldfield and Bullfrog passes the mill. A well and a spring supply an abundance of good water here.

283. *Bonnie Claire station, Nye County (B-5).*—This station is at the northwest edge of Sarcobatus Flat, about 35 miles south of Goldfield, on the stage road from Goldfield to Bullfrog, at an elevation of 3,973 feet (U. S. Geological Survey). Several wells that have been sunk 12 feet into the playa deposits yield a good supply of slightly brackish water. This station has taken the place of the old Thorp Mill and Summerville stations, about 2 miles farther south and now abandoned. Thorp post-office, originally located at Thorp Mill, has been moved to Bonnie Claire station.

284. *Tonopah Well, Nye County (B-5).*—This well is about $7\frac{1}{2}$ miles southeast of Bonnie Claire station, at the southwest edge of Sarcobatus Flat. A well about 20 feet deep has been sunk in the playa deposits, but the water is poor.

285. *Seattle Well, Nye County (B-5).*—This well is on the road from Goldfield to Bullfrog, about $1\frac{1}{2}$ miles south of the Tonopah Well and about $1\frac{1}{2}$ miles southwest of a dry lake bed. It is about 20 feet deep, but has no pump or windlass. The water is abundant and good.

286. *Farmer station, Nye County (B-5).*—Farmer station is a half-way house between Goldfield and Bullfrog, on the old private road of the automobile company. It is on the east side of Sarcobatus Flat, about 5 miles east of Bonnie Claire station. Private conveyances use the road by way of Bonnie Claire station, as they can find no water on the old automobile road until they reach the head of Amargosa River.

287. *Willow Spring, Nye County (C-4).*—This spring is about 4 miles a little east of north of the highest peak in the Grapevine Range, known as Grapevine Peak. It is on the north side of a high spur at the end of a wood road. There is another Willow Spring (No. 281) about 20 miles northwest, in Gold Mountain.

288. *Brier Spring, Nye County (C-5).*—This spring is about 3 miles south of east of Wahguyhe Peak, on the northwest slope of a big spur of the Grapevine Range, about 1 mile northwest of Mexican Camp No. 289, and 1 mile north of the Alkali Spring mentioned

below. There is a plentiful supply of good water. There are also springs in the first canyon due east of Wahguyhe Peak, and about 2 miles a little south of east of the peak. The water is abundant and good.

289. *Mexican Camp and Alkali Spring, Nye County (C-5).*—This is a wood camp in the Grapevine Range in the first canyon south of Wahguyhe Peak that drains into the Amargosa Desert, at the end of the wagon road about $1\frac{1}{2}$ miles east of the divide. It is about 13 miles north of west of Bullfrog, and $2\frac{1}{2}$ miles northeast of Nevada-California boundary post No. 91. The spring is small, with very little water. There is a trail from Mexican Camp to Death Valley by way of Titus Canyon, and on this trail about $1\frac{1}{4}$ miles southwest of the camp, one-fourth mile west of the divide on the north side of the trail, there is a small spring called Alkali Spring by some. The supply of water is small and its quality is poor.

290. *McDonald Spring, Nye County (C-5).*—This spring is on the east slope of the Grapevine Range, 10 miles a little north of west of Bullfrog, about $2\frac{1}{2}$ miles north of Cave Rock Spring (No. 291), and 1 mile south of a wood road on the south side of a small butte. The supply of water is small.

291. *Cave Rock Spring, Nye County (C-5).*—This spring is on the east slope of the Grapevine Range, about 10 miles a little south of west of Bullfrog, and 2 miles south of east of Nevada-California boundary post No. 92. It is well up the slope above the wash and accessible to wagons. The flow is about 4 barrels per day.

292. *Currie Wells, Nye County (C-5).*—This watering place is 10 miles northwest of Bullfrog, on the road from Goldfield, at an elevation of 4,401 feet (U. S. Geological Survey). Water is obtained from three wells, 10, 12, and 14 feet deep, yielding about 200 barrels of excellent water daily. There is a stage station here, at which meals and forage for animals can be obtained.

293. *Mud Spring, Nye County (C-5).*—These springs are about 10 miles north of Bullfrog and about 4 miles northeast of Currie Wells, on the south edge of Sarcobatus Flat. They have been extensively used by freighters and their location is clearly marked by camp debris. There is a fair supply of good water.

294. *Oasis Valley, Nye County (C-6).*—This is the name given to the valley in which Amargosa River rises. In it there are nearly 100 springs, which constitute the source of the river. These springs are scattered along the valley for about 6 miles and yield thermal as well as cold waters. Among them are the Oasis Springs, from which water is piped to the town of Bullfrog. This valley should not be confused with Oasis, a settlement in the southeastern corner of Mono County, Cal.

295. *Topopah Spring, Nye County* (C-7).—This is also called Black Rock Spring. It is about 15 miles northwest of Cane Spring (No. 298), high up on the south slope of Shoshone Mountain, on the east side of a basin bounded on the west by low "calico" hills. The supply of water is very meager.

296. *Railroad Tank, Nye County* (C-8).—This tank, or natural basin, is in the open valley about 20 miles due south of Oak Springs Butte, one-half mile west of White Mud Flat (a dry lake), and 13 miles north from Cane Spring (No. 298). The water is very alkaline, and the tank is usually dry in August.

297. *Rose's Well, Nye County* (D-6).—This well is near a station on the Las Vegas and Tonopah Railroad, being about half a mile west of the railroad, on the old stage road from Fairbanks Ranch to Bullfrog. The well is 210 feet deep and yields about 100 barrels per day of good water.

298. *Cane Spring, Nye County* (D-8).—This spring is on the old emigrant road from Salt Lake to Los Angeles, about 13 miles south of Railroad Tank, about 45 miles south of east from Bullfrog, and 25 miles northeast of Fairbanks Ranch. It is 30 miles by road northwest of Indian Springs station, on the Las Vegas and Tonopah Railroad. The water is good and the supply is about 25 barrels per day.

299. *Miller Well, No. 1, Nye County* (E-6).—This is a well dug by Mr. Miller, on the stage and automobile road from Las Vegas to Bullfrog. It is about 8 miles northwest of the Fairbanks Ranch, at an elevation of 2,555 feet (U. S. Geological Survey). The well is about 200 feet deep, and will supply 200 barrels per day. There is no rope, as the well has not been used since 1905.

300. *Fairbanks Ranch, Nye County* (E-7).—This is a well-known ranch and stopping place for travelers on the roads leading from Barnwell to Ivanpah, Cal., and from Roach and Jean, Nev., northward by way of Manse. The ranch is near the north end of Ash Meadows, at the southeastern edge of what is known as the Amargosa Desert. It has been occupied and cultivated for a number of years, and is supplied with an abundance of water from springs that suffice to irrigate a large tract. Both grain and provisions may be obtained here by travelers.

Roads lead from Fairbanks Ranch southeastward to Pahrump (35 miles away) and to Manse (40 miles away). There are no regular watering places between Fairbanks Ranch and Pahrump. Other roads toward the northeast and north connect with the main Las Vegas-Bullfrog road at Miller Well No. 2, and still other roads lead westward to Furnace Creek and the north end of Death Valley. Specific details as to all these roads can be had at the ranch.

301. *Miller Well No. 2, Nye County* (E-7).—This well, now abandoned, was dug by Mr. Miller on the stage and automobile road from

Las Vegas to Bullfrog and stands at an elevation of 2,490 feet. (U. S. Geological Survey.) It is about 6 miles northeast of Fairbanks ranch and about the same distance southwest of Amargosa station, on the Las Vegas and Tonopah Railroad. There is a building at the well, and until recently water has been sold to travelers. The well is about 70 feet deep and can supply 100 barrels per day. The water is brackish, and there is no rope at the well, which has not been in use since 1905.

302. *Johnnie, Nye County* (E-8).—This mining settlement has come into existence since 1902. It is about 18 miles west of north from Pahrump and about 12 miles southeast of Miller Well No. 2. Water is piped to the town from Horseshutem Spring, about 4 miles to the east.

303. *Kevichup Spring, Nye County* (E-8).—This spring is near the Johnnie mine, 5 or 6 miles northeast of the town of Johnnie. The water is used for the mining camp, and is said to be of excellent quality.

304. *Hornet Springs, Lincoln County* (E-9).—These springs are on the northeast slope of Spring Mountain, about 7 miles south of Elderberry and about 20 miles northeast of Manse, on a road from Manse to Indian Springs (No. 305). They yield a large supply of water of excellent quality.

305. *Indian Springs, Lincoln County* (E-9).—These springs are about 20 miles northwest of Corn Creek Spring, 35 miles east of Miller Well No. 2, and 45 miles from Las Vegas. They are more than 5 feet deep and yield an abundant supply of water, which issues from limestone. This is one of the important camping places on the stage and automobile road from Las Vegas to Bullfrog.

306. *Corn Creek Spring, Lincoln County* (E-10).—This spring forms another stopping place on the road from Las Vegas to Bullfrog. It yields from 1 to 2 miner's inches of excellent water.

307. *Pahrump, Nye County* (F-8).—Pahrump, one of the oldest settlements in the southern portion of Nevada, is about 7 miles northwest of Manse, on the road to Fairbanks ranch. It is a large ranch, in whose cultivation a number of Indians are employed. Here orchards, vineyards, and extensive fields of alfalfa flourish, and the water used in irrigation is supplied by a number of large, deep-seated warm springs, similar to those at Manse. Travelers can obtain hay and grain here.

308. *Manse Springs, Nye County* (F-8).—The springs at Manse have been known for years to travelers going northward from points in southern Nevada, and the place has long been the principal stopping point along this route. By the use of the water which the springs yield, this portion of the desert has been converted into a veritable oasis, and the 500 or 600 acres of alfalfa, orchards, and

vineyards show the capabilities of the desert soil when water can be applied to it in sufficient quantity.

The springs are over 20 feet in diameter and from 5 to 6 feet deep. The bottom is of white sand, and warm water boils up through this in large volume. These important springs and those of similar character at Saratoga Springs, Resting Springs, and Indian Springs, all occur along a line that runs nearly northeast and southwest. All of them are remarkable for the volume and purity of the water they yield.

311. *Mountain Spring, Lincoln County* (F-9).—This spring is about 4 miles, air line, southwest of Wilson's ranch, and on the other (the western) slope of Spring Mountain. It is about 8 miles northwest of Crystal Springs (No. 316), and is but little below the highest point on the road from Las Vegas westward to the Pahrump Valley. It is close by the roadside and its position is well marked. The supply of water is ample.

There are many springs in Spring Mountain, many of which are well known locally and may be reached by roads or trails from Pahrump, Manse, Las Vegas, and points on the San Pedro, Los Angeles and Salt Lake, and Las Vegas and Tonopah railroads.

312. *Tule Springs, Lincoln County* (F-10).—These springs are about 12 miles northwest of Las Vegas, on the road from Las Vegas to Bullfrog. The waters rise along the edge of a dry lake in the northwestern extension of Las Vegas Valley. They are the first springs to be found along this road beyond Las Vegas.

313. *Vegas Springs, Lincoln County* (F-10).—These are warm springs about 2 miles west of the city of Las Vegas. They yield a supply that is used locally for irrigation. Frémont stopped here May 3, 1844, and speaks of the waters as "two narrow streams of clear water, 4 or 5 feet deep, with a quick current, from two singularly large springs." The water has a pleasant taste, but is rather too warm to be agreeable, the temperatures being respectively 71° and 73° in the two springs.

314. *Mesquite Springs, Lincoln County* (F-11).—These springs are about 10 miles southeast of Las Vegas, on the south road leading thence to Callville. The water supply is reported to be good, and the position of the springs is clearly marked by camp rubbish. Mesquite Wells (No. 320) are in Mesquite Dry Lake, about 35 miles southwest, on the western edge of the State.

315. *Stump Spring, Lincoln County* (G-9).—This spring is about halfway between Sandy and Manse, on the old stage road from Ivanpah to Manse. It is protected by curbing, and the water must be drawn by a bucket. Roads from Stump Spring lead westward to Resting Springs, and eastward to Las Vegas, both by way of Crystal Springs (No. 316) and by way of Wilson's ranch (No. 317).

316. *Crystal Springs, Lincoln County* (G-9).—These springs are in a pass between two ranges that have only local names, about 8 miles southeast of Wilson's ranch. They are plainly marked, as they have been used for many years by the settlers.

317. *Wilson's Spring, Lincoln County* (G-10).—This spring is on the well-known Wilson ranch, about 20 miles south of west from Las Vegas, on the road from Las Vegas to Stump Spring. The water is used for irrigating the ranch.

318. *Cottonwood Springs, Lincoln County* (G-10).—These springs are 4 miles southeast of Wilson's ranch and about 18 or 20 miles southwest of Las Vegas, on the old wagon road from Las Vegas to Good Springs or Jean station. The water is good and its amount great enough to irrigate a small ranch.

319. *Sandy, Lincoln County* (H-9).—Sandy, a mining settlement and post-office, is on the old stage road from Ivanpah to Manse. It is about 1 mile north of Mesquite Dry Lake and about 16 miles west of Good Springs or Jean station, on the Salt Lake Railroad. Water is to be had at several near-by points east and south, but on the road running northward the nearest water is found at Stump Spring, about 18 miles away. There are stores in the settlement, where supplies may be obtained.

320. *Mesquite Wells, Lincoln County* (H-9).—These wells are in a clump of mesquite trees in Mesquite Dry Lake, about 3 miles south of Sandy post-office, on the stage road from Ivanpah to Manse. They are protected by curbing, and the water stands so near to the surface that it is easily drawn up in a bucket. The quantity is sufficient and the quality fair.

321. *New England Springs, Lincoln County* (H-9).—These springs are between Jean and Sandy, on the road connecting the two points. At the springs a branch road turns northward to Crystal Springs and Wilson's. The flow of the springs is estimated at 1 or 2 miner's inches.

322. *Good Springs, Lincoln County* (H-10).—These springs are on the road to Sandy post-office, about 6 miles west of Jean station. There are large mines in operation near by, and a settlement has grown up around them. The supply of water is large and its quality is indicated by the name.

323. *Piute Springs, Lincoln County* (I-11).—These springs are about 13 or 14 miles from Barnwell station (Manvel post-office), just east of the California-Nevada line, in the Piute Range. The main road from Barnwell to Searchlight runs about 3 miles north of them, but there is a dim trail between these places that passes the springs. Their exact location can best be ascertained by inquiries at the railroad station. The water issues from the granite that forms the axis of this range, and is pure and sweet. Other Piute Springs (No. 149) lie in Piute Pass, about 20 miles south.

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GOVERNMENT PRINTING OFFICE
1909

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

WATER-SUPPLY PAPER 225

GROUND WATERS
OF THE
INDIO REGION, CALIFORNIA
WITH A SKETCH OF THE
COLORADO DESERT

BY
WALTER C. MENDENHALL



WASHINGTON
GOVERNMENT PRINTING OFFICE
1909

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GROUND WATERS OF THE INDIO REGION, CALIFORNIA, WITH A SKETCH OF THE COLORADO DESERT.

By **WALTER C. MENDENHALL.**

INTRODUCTION.

Water is the first requisite to the existence of all life; hence everywhere in the arid West the question of water supply is of paramount importance. Agricultural and industrial activity can not continue without water; mining is seriously handicapped by small supply; and in the more arid districts generally all hope of permanent human occupation depends upon the possibility of developing or introducing water in relatively large quantities.

Those deserts whose watering places are widely separated are dreaded by travelers and, if possible, avoided. The number of desert tragedies has not been reduced by the building of railroads within the last quarter century, because the lessened danger has been balanced by a greater influx of inexperienced travelers.

The Colorado Desert in southern California is one of the most sensationally interesting as it has been one of the most truly arid parts of western North America. Since the first journeys were made across it by the mission fathers to extend the influence of their church from the older settlements in Mexico and New Mexico westward and northward into California, it has been in ill repute among travelers.

For more than a hundred years travel between the settlements east of Yuma and those on the California coast north of San Diego has followed a highway that crosses this desert. By this route the missions of Mexico, New Mexico, and Arizona were connected with those of San Diego, San Luis Rey, Capistrano, San Bernardino, San Gabriel, and San Fernando. After the Mexican cession and before the building of the great railways a transcontinental stage route crossed it, and American traders occasionally drove freight teams from Yuma to San Bernardino along a course which was later followed closely by the Southern Pacific Railroad. This longer road, which traversed the desert from end to end, was less generally used than one which crossed it from east to west and entered the mountains by way of San Felipe Creek and Warners Valley, so reaching

San Jacinto and later Los Angeles with less of desert and more of mountain travel.

EXPLORATION AND DEVELOPMENT OF COLORADO DESERT.

One of the most satisfactory published accounts of the Colorado Desert is that prepared by the first of the American scientific explorers who have visited it. In 1853 a military expedition, led by Lieut. R. S. Williamson, explored the southern part of the San Joaquin Valley, the passes leading from it to the Mohave Desert, those connecting this desert with the valley of southern California, and, finally, those which connected that valley with the Colorado Desert. The primary object of the expedition was to determine feasible routes for railroad construction, but, as was usual at that time, a naturalist was attached to the expedition to report on matters of scientific interest that might be observed along the route of travel. This assignment was held by Prof. William P. Blake, and the report ^a which he published after the expedition had been disbanded presents the most complete and graphic scientific account of the physical features of this section of arid America that is yet available.

The party to which Professor Blake was attached entered the desert from San Bernardino through San Gorgonio Pass. The first stop was made at Palm Springs and the second at Indian Well, in the northwestern end of the desert, now usually called the Coachella Valley. The explorers visited the springs at Toro and Agua Dulce, which have since been included in the Indian reservations and were then centers about which Indian habitations were clustered. Below Figtree John's the expedition encountered difficulties in its attempt to reach the old stage road which followed Carrizo Valley from the desert floor to the base of the Peninsula Range. Along the west side of Salton Sea there is a wide area in which potable water was at that time very scarce, and it was only after several of the animals of their pack train were nearly exhausted that the members of the expedition finally found water in the vicinity of Salt Creek, near what are now known as "McCain Springs."

Professor Blake describes the physical aspect of the desert, the effects of wind erosion upon it near Palm Springs, the old water line along the western border, and such other geological phenomena as were observed; and he mentions the springs which he visited during his journey or about which he could obtain reliable information. It is interesting to note that in the course of his discussion he predicted

^a Reports of explorations and surveys to ascertain the most practicable and economical route for a railroad from the Mississippi River to the Pacific Ocean, made under the direction of the Secretary of War in 1853-54, according to acts of Congress of March 3, 1853, May 31, 1854, and August 5, 1854: Sen. Ex. Doc. No. 78, 33d Cong., 2d sess., vol. 5, pt. 2; Geological report by Wm. P. Blake, geologist and mineralogist of the expedition.

that artesian water would be found beneath the surface of the desert. Thirty-five years afterwards this prediction was fulfilled, although the waters are found in the Pleistocene alluvium instead of in the consolidated Tertiary rocks, where Professor Blake expected that it would be found.

The desert was made much more accessible in 1879 by the construction through it of the main line of the Southern Pacific Railroad from New Orleans to San Francisco. Extensive travel across it by wagon ceased with the construction of the railway, and at the various stations along the line water may always be procured, so that the danger of death from thirst has been greatly reduced.

In 1888 the Southern Pacific engineers, in searching for water for their locomotives and station houses, obtained small artesian flows at Thermal and Coachella. Six years later a successful well was put down at Walters, now called Mecca, thus proving definitely the existence of water under this portion of the desert basin with sufficient pressure to rise to the surface. Attempts to sink wells with the ordinary well rigs in use in adjacent parts of southern California are not, however, attended with success here, because of thick strata of fine sand, through which it has been found extremely difficult to sink the casing and keep the tube in alignment by the standard methods. Experiment has proved, however, that the hydraulic method, in use for shallow wells in the coastal plain of southern California, is well adapted to this desert region. As a result of this discovery numbers of successful wells have been sunk, and the reclamation of the northwestern arm of the Colorado Desert is under way (Pl. X, A, B, and C) through the utilization of the waters thus developed.

At about the same time that the underground waters began to be used extensively about Indio, the California Development Company, by utilizing an old distributary of Colorado River, carried waters from that stream to a part of the desert that lies in Imperial County, near the Mexican line, and that is now called the Imperial Valley. When this water had been successfully conducted out upon the old desert floor it was found that the soils over much of the area were very fertile. Settlers hastened to the region, successful ranches were established, and now several thousand people are living in the heart of what was once a most dreaded waste. Thus the transformation of the southern, broader end of the Colorado Desert was begun.

GEOGRAPHY.

The Colorado Desert lies in a wide valley, the northwest extension of the great depression whose southern end is occupied by the Gulf of California. (See Pl. I.) This valley extends northward to San Geronio Pass, in Riverside County, 200 miles above the present

head of the gulf. It is bounded on the west by the **Peninsula Range** and on the east by a network of desert ranges, known in their various parts as the Cottonwood, the Ironwood, and the **Chuckawalla Mountains**. The Peninsula Mountains do not present a regular front toward the desert. This eastern face of the range exhibits a series of salients and reentrants, which result in great steplike irregularities in the western wall of the valley. The first and least prominent of the salients seen in passing from San Gorgonio Pass southward is formed by the eastern base of San Jacinto Mountain. Back of it lies the lower valley of Palm Canyon, whose width increases that of the desert to 9 or 10 miles.

The next of the great Peninsula salients is formed by the Santa Rosa ridge, whose southern end lies just west of the Salton Sea. Back of this lies Borego Valley and the canyon of Coyote Creek. At this point the width of the desert increases to 35 miles. Still farther south Carrizo and Black mountains form another salient, and below them the desert attains its maximum width of nearly 50 miles. At the international boundary is Signal Mountain, a northern outlier of the Cocopa Range, which divides the lower portion of the desert into an eastern part, occupied by the Colorado delta, and a western part, lying below sea level at its lowest point and containing the Laguna Salada, a fluctuating body of bitter water.

The barren ranges that form the eastern wall of the desert are the southeastern continuation of the San Bernardino Mountain mass. They are irregular in arrangement and altitude, but there is not the system in their irregularity which is displayed by the Peninsula Range. They are interrupted by high passes, by which they may be traversed to the valley of the Colorado River of the West, which lies east of them; and in a general way they diminish in altitude toward the south until, in the vicinity of Yuma, they disappear, and the desert unites around their southern end with the valley of the Colorado River. These mountains are typical arid ranges, barren of all normal types of vegetation. Here and there characteristic distorted desert growths, like the barrel cactus, the ocotilla, the cholla, the greasewood, the ironwood, and the palo verde are found sparingly distributed over the rocky mountain sides.

The lower slopes of the Peninsula Range west of the desert are as barren as the mountains east of it, but as the crest is approached the more humid conditions which prevail on the Pacific slope and extend for short distances over the crest toward the desert produce more abundant vegetation. Conifers of a few types, palms in some of the lower, better-watered canyons, grasses, the hardier varieties of chaparral, and other common southern California plant forms are found. Needless to say, practically all the perennial streams that flow to the desert rise on the upper slopes of the ranges to the west and north of it.

The floor of the desert itself exhibits various physical aspects. The portion first reached in passing into it from Redlands or San Bernardino is a region of sand dunes. Practically the entire valley bottom here is a waste of shifting sand, in almost constant motion through the action of the strong winds that blow at frequent intervals from San Gorgonio Pass and the high mountains which flank it on the north and south.

Just south of the sand-dune area and below the sea-level contour the valley floor is silt covered, relatively smooth, and sustains a luxuriant growth of desert vegetation. The mesquite bush here attains the dignity of a tree, and forms which are dwarfed in less fertile and drier sections of the desert here grow luxuriantly, because the artesian waters, imperfectly confined beneath the partially pervious clays that underlie the surface, seep toward it and furnish a supply of moisture which for these desert plants is unusually abundant.

Farther southeast, about the borders of the Salton Sea, strongly alkaline areas are found, and here the desert floor, smooth or sharply gullied and gently sloping, is generally devoid of vegetation. At the lowest point in the valley, now occupied by the Salton Sea, the alkalies had accumulated to such an extent as to form a true "salina," and salt was mined there in a commercial way for many years before the inflow of the Colorado.

Still farther south, beyond the Salton Sea, in the region now known as the Imperial Valley, the desert is floored with a fine laminated silt, deposited in past centuries by the Colorado River. This region appears level to the eye, but in reality slopes toward the Salton depression. Before irrigation and settlement only indefinite channels, seldom filled with water, extended from the area of annual summer overflow in the vicinity of the lower Colorado toward the sink; but in the last few years two of these channels—New and Alamo rivers—have been deepened and enlarged, until they are now continuous deep cuts with wall-like banks from a point south of the Mexican line to the shores of the new lake.

As a physical feature the Colorado Desert is continuous from San Jacinto Peak southeastward to the head of the Gulf of California. As a result of settlement and the attendant development, however, different portions of the lowland have been given different names, which have no physiographic significance but are based entirely upon human occupancy. The Imperial Valley, the most important of these subdivisions, has been outlined. It occupies the southernmost part of that portion of the Colorado Desert lying within the United States. The northern, narrow end, lying between the base of San Jacinto Peak and the margin of the Salton Sea, is known as the "Indio region," or the Coachella Valley. The fertile and cultivated portions of this section lie, for the most part, south of Indio and

below the sea-level contour, settlement and development being controlled entirely by the occurrence of underground waters, which are most abundant and accessible within the limits outlined above.

East of Imperial Valley and extending from Mammoth station southward to the international boundary is a belt of sand dunes, 6 or 7 miles wide and 40 or 50 miles long, lying east of the well-marked old beach line, while west of the valley is the sandy beach marking the western shore of the old lake, between which and the base of the mountains is a belt of alluvium, such as usually borders desert mountains.

GEOLOGIC SKETCH.

STRUCTURAL FEATURES.

The west wall of the Colorado Desert from the vicinity of Banning to the southeastern point of the Santa Rosa Mountains is made up exclusively of massive plutonic rocks of granitic or acid dioritic type, and of metamorphic rocks which are intruded by the igneous masses. The axis of the San Jacinto Mountains appears to consist of an unaltered dioritic mass, about whose periphery there is a zone of schist and gneisses with occasional bodies of highly altered limestone. These metamorphic rocks are found along the southern border of the desert in the vicinity of White Water and Palm Springs, and are believed to exist some miles east of the latter point, along the southern border of the Conchilla Desert. The projecting points in the neighborhood of Indian Well and at places farther south, toward Toro, are formed of massive granitic rocks, but still farther south, back of Figtree John's, the wall of the Santa Rosa ridge again proves to be geologically more complex. Diorites occur in this vicinity in small masses, but basic schistose rocks and marmorized limestones are found in large bodies.

None of the rocks of this type have any value as water bearers. So far as water in commercial quantities is concerned they are practically impervious. East and west of these metamorphic and intrusive masses much younger rocks of totally different character cover extensive areas. West of the San Jacinto mass blue and buff shales, with occasional traces of vegetal remains and of fresh-water shells, extend along the ridge between San Timoteo Canyon and the San Jacinto Valley nearly to Colton. These impervious shales are overlain unconformably by heavy bodies of alluvium made up of well rounded river cobbles, sands, and clays intermingled or in alternating beds. In this region the attitude of these rocks and their porosity make them valuable water bearers, and in the Yucaipe Valley and San Timoteo Canyon near Redlands deep wells have been drilled in them which yield water in sufficient quantities



RED CANYON, NORTHEAST OF MECCA.

to irrigate near-by lands. The age of these consolidated sediments is not known with certainty, but it is probably Pliocene.

East of the point of the Santa Rosa Mountains rocks that are similar in general character though probably older, but about the details of whose distribution and structure very little is known, extend southward to the Mexican boundary. These areas were traversed by Professor Blake from the Santa Rosa Mountains to Carrizo Creek, and in his report upon that region he describes them as highly folded and exhibiting the usual Tertiary sedimentary succession of sandstone and shale.

More detailed work has been done in the vicinity of Carrizo and Black mountains by the writer, and something has been learned of the stratigraphic sequence and of the structures there. The basal members of the sedimentary series in Carrizo Mountain are usually conglomerates of limited thickness, 100 to 200 feet being about the usual measure. Overlying these are buff and greenish shales which are at least 1,000 feet thick, and may be much more. They are succeeded in turn by a body of soft shales, which in places show a pink tint and are interbedded with thin brown concretionary sandstones. These have a wide distribution over the western margin of the desert between Carrizo Mountain and the Cocopas. A few springs occur along the outcrop of the sandstone members of this series, but water in sufficient quantity and purity to be valuable for irrigation has not been developed in them, although a number of wells drilled in prospecting for oil have penetrated the rocks to depths of a thousand feet or more.

The age of the basal members of this sedimentary series in the Carrizo Valley is Miocene. The higher beds may be somewhat younger. The core of Black and Carrizo mountains which has served as a basement on which the sediments have been deposited, like the main range farther north and west, is a complex of metamorphic rocks and massive intrusives. Small patches of effusive lavas and associated tuffs also occur in this section, overlying the basement complex and interbedded in places with the lower members of the sedimentary series.

North and east of the Colorado Desert the relations are in a general way similar to those on the south and west sides. At the base of the north wall of San Gorgonio Pass is a belt of folded and faulted alluvial sediments, not more than 2 or 3 miles wide, which locally has been cut down by erosion and buried under modern wash. Wherever it remains, however, and is exposed for examination the rocks are seen to be coarse sandstones, gritty clays, and heavy conglomerates which have been thrown into complex attitudes and broken along many lines.

North of the sediments are the schists and massive rocks that make up the main body of the San Gorgonio Mountain mass. The

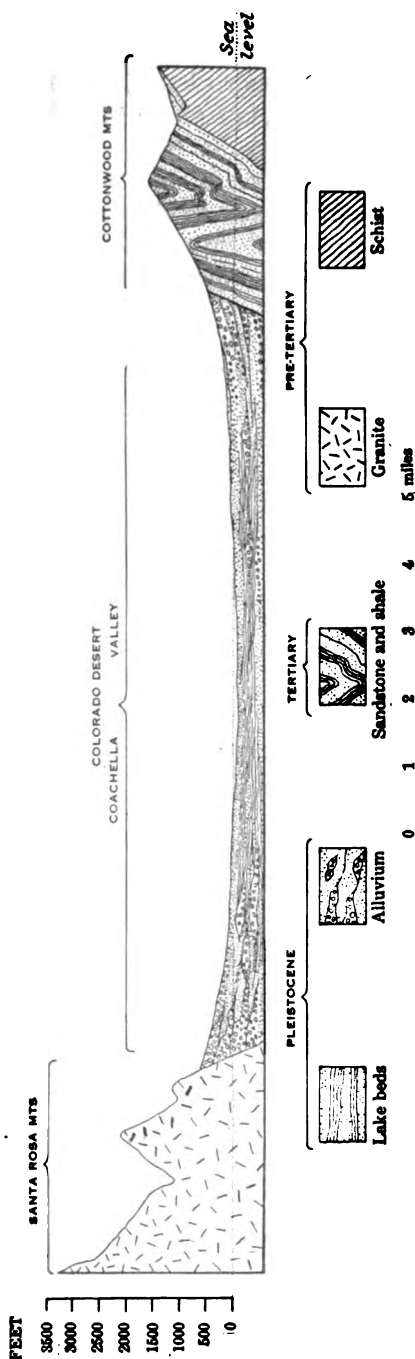


FIG. 1.—Diagrammatic section across Coachella Valley through Mecca.

contact between the metamorphics and the sediments here is a fault contact. North of Indio the normal valley filling of unconsolidated lake sediments and alluvium extends for a distance of approximately $2\frac{1}{2}$ miles; beyond this lies a range of low foothills formed of folded Tertiary sediments, somewhat similar in general aspect to those in San Geronio Pass but not so coarse, probably because they lie at a greater distance from the source of the material of which they are composed. They are closely folded here, as elsewhere, and the exposures are so perfect that the succession of synclines and anticlines can be traced with the greatest exactness (fig. 1).

The northern wall of the valley back of Mecca has also been examined. Here a space of perhaps $2\frac{1}{2}$ miles intervenes between the railroad and the first bed-rock exposures. The section of folded Tertiary beds and their relations to the older rocks are plainly shown in the box canyon that opens on the desert almost due north of Mecca (Pl. II). The basement rocks exposed near the head of this canyon are highly altered schists containing acidic dikes and quartz stringers. Directly upon these, with a normal depositional contact, rest from 1,000 to 1,200 feet of dark brownish-red sandstones and conglomerates (Pls. II and III,

B, and fig. 1). Overlying these, apparently conformably, are from 3,000 to 4,000 feet of yellowish sandstones and sandy shales containing masses of coarse conglomerate and alluvial material (fig. 1).

These sediments are all closely folded. They dip from the base of the beds toward the valley for $1\frac{1}{2}$ miles, but this dip is interrupted just at the valley border by a sharp anticline, which brings to the surface again many of the beds that had passed below it at points farther north. No fossils have been observed in any of these sediments north of the desert, and as they are alluvial in character and probably in large part fresh-water deposits, they are unpromising fields in which to search for organic remains. For the same reason they are not regarded as particularly promising as sources of oil or gas. It is probable, however, that the porous rocks in the synclines contain small quantities of ground water, and that this water would flow to the surface if tapped at favorable points, but its quality is problematic. The waters of the Tertiary rocks generally in this part of the State contain much alkali in solution, and at many places are unfit for drinking or even for irrigating purposes.

This belt of folded sediments extends along the east side of the valley at least as far as Imperial Junction, but is less conspicuous than farther northwest because it has been worn down more completely by erosive action. Usually, however, it forms a zone between the higher desert mountains of metamorphic rock, from which it may be separated by a belt of overlying alluvial fans, and the relatively level lands of the central desert.

Between Imperial Junction and the Salton Sea are isolated outcrops of sandstone, and another outcrop within the valley is but a few miles northwest of the town of Imperial, near the bank of New River. This outcrop is nearly in line with Superstition Mountain, west of the river. This mountain is reputed to have a granitic axis and to be flanked by sediments, and the outcrop near Imperial is considered as the southeastward extension of the same ridge.

Besides these sedimentary rocks it is to be noted that a row of knobs of obsidian, pumice, scoriaceous lava, and tuff extends southwestward for several miles from a point about 6 miles west of Imperial Junction. Originally these masses stood out merely as rock knolls in the desert; now they are islands in the Salton Sea. These rock outcrops near the south end of the Salton Sea suggest that the valley filling may be relatively shallow here—that is, that bed rock may be nearer the surface than either north or south of this locality.

The relations between the sediments and the metamorphic complex that forms the desert ranges east of the valley were observed only in San Gorgonio Pass and at a point a few miles east of Mecca.

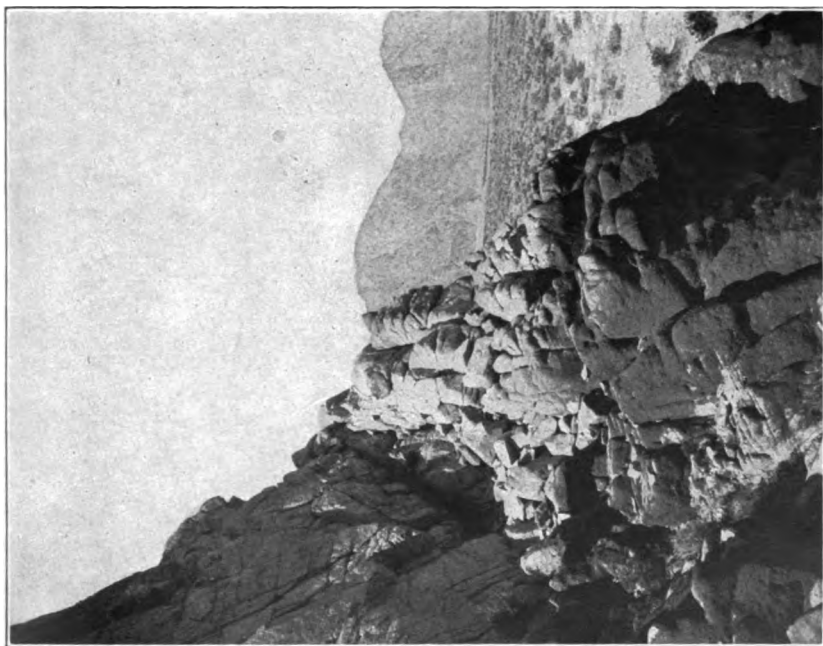
In the pass extensive faulting has taken place, and one of the fractures is between the sediments and the older rocks. Back of Mecca, however, a normal depositional contact is found, a true basal conglomerate forming the lowest member of the sedimentary series (Pl. II). The same conditions have been observed about Carrizo and Black Mountains, and are inferred at the southern end of the Santa Rosa group from general relations. Hence if the great Cajon-San Gorgonio fault extends into the desert it probably follows its axis closely, since it is not to be found along its borders. Here it is buried completely beneath the modern lake sediments, and its presence can be inferred only from isolated phenomena like the obsidian cones near Imperial Junction, with their accompanying solfataras, or from general physiographic evidence.

A sketch of the geologic phenomena of the desert would not be complete without further mention of these solfataras (Pl. IX). About 7 miles a little south of west of Imperial Junction, near the row of obsidian knobs already described, an interesting group of mud volcanoes existed before the area was flooded by the rising of the lake. Some of these were quite perfect cones with craterlets at top, others were in various stages of formation or destruction. The usual accompaniments of hot pools, gaseous emanations, sulphur and salt deposits, acidulated waters, and boiling mud pools were to be found here. Near the principal group were smaller groups of extinct or at least quiescent mounds. These mud volcanoes are regarded as representative of the last phase of the volcanic activity that produced the lava knobs in this part of the desert.

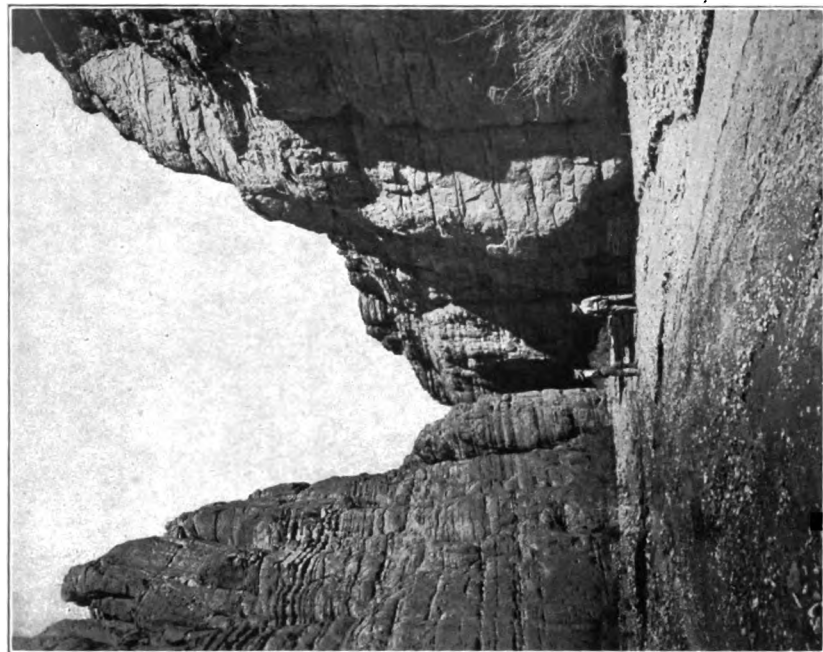
A more extensive field of mud craterlets is found about 40 miles south of the international boundary line, along the western shore of Volcano Lake. The forms that result from the activity and the phenomena generally are similar to those near Imperial Junction, but on a larger scale.

ORIGIN OF THE DESERT LOWLAND.

Of the details of the origin of the valley occupied in its southern part by the Gulf of California and at its northern end by the Colorado Desert, but little is known. It may be said, however, as a generalization, that it belongs to a type which physiographers describe as constructional—that is, it represents an area which has been depressed as a result of crustal movement, as contrasted with valleys due to erosion. There are many proofs of this. The fact that its rock floor is below tide, even in those parts north of the gulf where the actual surface is well above sea level, proves that a part at least of its position is due to actual subsidence of a block of the earth's crust, because erosive action can not extend below the ultimate base level, which is usually sea level. Wells drilled near Imperial indicate that



A. CALCAREOUS INCRUSTATION ON GRANITE ALONG OLD WATER LINE.



B. CANYON CUT IN TERTIARY ALLUVIAL SANDSTONES NORTHEAST OF MECCA.

there is no bed rock within a depth of 600 or 700 feet below tide, and others in the Coachella Valley and at Salton prove that at these places bed rock is at least 1,000 feet below sea.

The topographic character of the western margin of the desert within the United States and near the international boundary also indicates very distinctly the presence of fault lines along this margin. The eastern edge of the Peninsula Mountains is a marked fault scarp, throughout at least a portion of its length. The valley occupied by the Laguna Salada, west of Calexico, appears to be a dropped block. Salients like the Santa Rosa Mountains and the group south of San Felipe Creek; projecting toward the desert from the northwest, appear to be limited on one or the other side by faults. The Santa Rosa ridge itself is a particularly suggestive mountain mass. It has a steep, abrupt southwest face, with short drainage lines, and a relatively smooth and sloping northeast face, with long drainage lines. On its northeast face there are many large surfaces, comparatively unscarred by modern arroyos, which at once suggest remnants of an old eroded surface. In short it has the topographic characteristics of a faulted block tilted toward the northeast and plunging into the desert toward the southeast.

Little is known of the eastern desert border, but where it has been visited in the vicinity of Mecca there is no evidence of faulting, the rocks of which it is made up dipping toward the desert away from the old crystalline surface upon which they were deposited.

One of the most extensive faults in California runs southeastward through the coast ranges, north of the San Gabriel Mountains, through Cajon Pass, south of the San Bernardino Range, and through San Geronimo Pass into the Colorado Desert. Here it is no longer traceable; but since, if projected, it would follow closely the axis of the desert valley, through the Salton Sink and southeastward toward the Gulf, it may well be even here one of the lines of weakness that has helped determine the position of the depression. As the entire basin is occupied by lake silts and alluvium of most recent origin, it is evident that unless movement had taken place along this fault at a very late date there would be no surface indication of it. Phenomena like the obsidian buttes 6 or 8 miles southwest of Imperial Junction and the group of solfataras seen there until submerged by the waters of Salton Sea may well be associated with a profound fracture of this nature. The other group of solfataras, 35 or 40 miles southeast of Calexico, near the base of the Cerro Prieto in Mexico, is distributed for 2 or 3 miles along a northeast-southwest line, parallel to the structures in the mountain ranges to the west.

All of this evidence, taken together, indicates strongly that the desert valley is associated with structures in which faults are prominent, and leads logically to the conclusion that the desert is a con-

structional depression due to the marked and probably irregular subsidence of a number of faulted strips.

The Tertiary (Miocene?) rocks which border the desert on either side seem, so far as their relations are known, to have been affected by much of the movement in which the desert originated. Carrizo Mountain, on the western margin of the desert, about 12 miles north of the Mexican line, is a knob of crystalline rocks surrounded by Miocene sediments that dip away in all directions at angles greater than the original angle of deposition. About 7 miles south of Carrizo Mountain the crystalline rocks of the main range are not flanked by Tertiaries, but pass directly beneath the alluvial cones of the desert border, as though the sediments had been faulted out there. Signal Mountain is flanked by late sediments on the north and south at least, and they have been folded in varying degrees of intensity. This same observation applies to the sandstones and shales that flank the Santa Rosa Mountains on the southeast, south, and west; and along the eastern border of the desert, wherever the sediments are exposed, from Whitewater River well down toward Yuma, they have been closely folded. One section studied (fig. 1) from Mecca northeastward to the crystallines, shows that the sediments rest directly upon the schists as they were originally deposited and dip from them toward the valley, the regular dip in this direction being interrupted by a single well-marked anticline. As a rule, then, the Tertiary sediments dip from the valley borders toward its axis, and, as a rule, also, along its axis they are well below sea level and are deeply buried under recent alluvium.

Distinctly within the valley, yet not far from its borders, are a few isolated exposures of the Tertiary bed rock that presumably forms its floor almost everywhere. Around some of the obsidian cones southwest of Imperial Junction lie beds of upturned and somewhat altered material that may represent a part of the valley basement, although it is more likely that they are a part of the Pleistocene filling indurated by volcanic action. Between these cones and the railroad are occasional exposures of sandstones that belong clearly to the Tertiary series. Beyond Imperial Junction to the east, north, and northwest are the folded clays and sandstones that make up the valley margins generally. Here, however, they are planed off to an even surface that slopes toward the lake.

A few miles west of Imperial, near the east bank of New River, is a single exposure of sandstone of the type familiar about Superstition Mountain. Indeed, it probably represents merely an extension to the southeast of the Superstition ridge. Elsewhere, so far as known, there are no rock exposures near the axis of the valley.

The conclusions as to the origin of the great depression occupied by the Colorado Desert and the Gulf of California, in so far as they

can be drawn from evidence at hand, are, then, that it is due to crustal movement—subsidence along a number of fault lines, or, perhaps, slight subsidence in this area combined with elevation in the areas east and west, leaving the desert not far below its original position; that at least a part of this movement has taken place since the Tertiary rocks were deposited—fossils prove the presence of Miocene beds, and clearly later rocks are probably Pliocene—and as associated solfataric phenomena and the derived land forms are so well preserved, it is likely that much of the movement is late Pliocene or Pleistocene.

LATE DEVELOPMENT OF THE COLORADO DESERT.

At a period that is geologically very recent indeed the long, narrow depression whose origin has been thus briefly indicated was occupied by the Gulf of California to a point far north of the present head of the gulf. It is probable that the gulf waters then swept inland to the base or nearly to the base of San Jacinto Peak, although all evidence which would enable us to fix its exact limits has been obliterated by still more recent geologic events. At that time the mouth of Colorado River was in the vicinity of Yuma, 60 miles in an air line north of where it now is. Presumably then, as now, it was discharging annually enough silt to cover 1 square mile to a depth of 53 feet with dry earth, equivalent to 1 cubic mile each century, cut from the great canyons in the upper Colorado and the Gila Valley and carried to the gulf. Running water will carry in suspension matter that quickly settles in still water, the settling process in this case being aided by the clarifying effect of the salt water.

As a result of these processes the Colorado delta was gradually extended southwestward toward the Cocopa Mountains, and when it reached them it had separated the old gulf into the present gulf and an inland sea. Delta growth, however, did not cease with the separation of the water body into two parts. Silt continued to be brought down the stream and to be deposited in its bed, along its banks, and in the still waters at its mouth. A stream by this process of deposition along its channel eventually builds the channel up until it is higher than the lands adjacent on either side. It is then in a condition of unstable equilibrium, and at some favorable time, as during an exceptional flood, it will break out of its immediate banks, and establish itself in some more favorable course. By this process, often repeated, it comes eventually to flow over all parts of its delta, building up each part in succession. By such a process the Colorado must have discharged alternately into the gulf and into the depression now known as the Salton Sink, meanwhile building up the delta

dam that separates them until it reached a height of about 40 feet above sea level. During this process it is highly probable that water filled the Salton depression and evaporated from it many times, for it must have quickly disappeared whenever the erratic river changed its course to the gulf, for the run-off from the mountains that surround the sink is too slight to maintain a permanent water body in this region of intense evaporation. Meanwhile the original body of salt water that occupied the sink had been displaced by the volumes of fresh water poured into it from the river, and in the intermediate stages of the lake's existence, at least, its water was fresh or nearly fresh. A clear and definite indication of the last occupancy of this depression by a lake, presumably just before the river had shifted to the course that it now follows to the gulf, may be seen in the remarkably well-preserved old water line that rims the desert from Indio to the Cerro Prieto at a height of 40 feet above sea level (Pls. III, A, IV, and V). On the rocky points that projected into the lake it is marked by a thick deposit of calcium carbonate (Pl. III, A), by slightly cut sea cliffs, and by a change in the profile of the rocky spurs at the water line. Where alluvial cones and the sandy floor of the desert formed the shore line, beaches have been developed, and although of soft sand, easily eroded, they are even now well preserved, thus testifying to the recency of the action that produced them. Over the floor of the desert and along the sandy beaches are myriads of shells of fresh or brackish water mollusks^a that lived in the lake.

There are some reasons for thinking that the lake at this latest stage was not perfectly fresh—that its waters were at least distinctly "hard." Its area, when it stood at 40 feet above sea level, was somewhat in excess of 2,100 square miles. The average flow of the Colorado has been determined as about 11,000,000 acre feet per annum. The evaporation from a surface of the area of the old lake, under the conditions that prevail here, has never been determined, but is undoubtedly high. If it is as high as 8 feet per annum it would nearly equal the average annual inflow from the Colorado; if it is but 7 feet per annum the average inflow would exceed the evaporation by 2,000 second-feet, or somewhat less than 14 per cent of the inflow. In either event the waters of the lake would be markedly more alkaline after a term of years than those of the Colorado. The calcium carbonate incrustations (Pl. III, A) on the rocky points about the shores of the old lake are best explained by supposing that the lake waters contained large quantities of this salt, so that wherever they broke in spray and evaporated more rapidly than usual the carbonate was deposited. This necessary excess of inflow

^aStearns, Robt. E. C., Remarks on fossil shells from the Colorado Desert: *Am. Naturalist*, vol. 13, pp. 141-154.



THE "WATER LINE" ABOUT THE BASE OF A GRANITE OUTLIER SOUTHWEST OF COACHELLA.

over outflow at the period of maximum area of the lake, taken in connection with the thick calcium carbonate incrustations on the shores, indicates distinctly hard water. It may be assumed that other salts than calcium carbonate were also present in large amount, for the conditions that would lead to an abundance of the one salt would also lead to an abundance of the others. The shells so thickly distributed over the desert floor, however, are not salt-water forms, but are identical with those now found living in the springs and occasional permanent streams about the desert borders. Many of these springs and streams are somewhat brackish, and the creatures flourish in them. It seems probable, then, that the lake waters also were rather alkaline, perhaps even brackish, at the time when the lake attained its maximum area.

The period at which this lake disappeared can not be precisely fixed. The time units of geology are too large and too indefinite to translate satisfactorily into years, so that when we say that the disappearance of the lake is the most recent of geologic events we still leave the mind groping for a definite human standard of time. The sandy beaches which mark the borders of the ancient lake are cut away, to be sure, where washes cross them from the mountains, but in sheltered places they are still perfect. Where they stretch across an embayment from one rocky point to another they are mere embankments of sand, old barrier beaches, with depressions behind them once occupied by shallow lagoons. In other areas, where they contour the alluvial cones, they are gullied and cut away where streams have flowed across them, but in other places are preserved unscarred. At one locality noted a low sea cliff that had been cut in alluvial-fan material was still preserved, although the loose sand and boulders would slump in a few heavy storms.

In a region of abundant rainfall such ephemeral forms as these would be more nearly obliterated within fifty years after the lake had disappeared than they now are in the desert. In such a region the precipitation is twenty times that of the desert. It is the crudest of estimates—merely a guess in fact—to state that, reasoning from geologic evidence alone, it may be a thousand years since the lake disappeared, yet it puts in concrete form such a guess as the geologist is able to make, and this guess may be correct within a margin of error of 50 per cent.

When human records are studied some evidence on this point is found, but it is almost as uncertain as to time as that furnished by the physical features. The Indians in the Coachella Valley have distinct legends to the effect that at some time in the past the valley was occupied by a large body of water. Professor Blake records that they told him of a time when a great water body existed in which

were many fish, and of the manner in which that water disappeared "poco á poco"—little by little—until the lake became dry.

The Indians now living in the desert put this event as far back as the lives of four or five very old men, say four or five centuries ago at the most. There are, of course, no records and there is no known check on this assertion. Statements by Indians as to time, beyond the limits spanned by their own memories, are notoriously inaccurate. Furthermore, we do not know the means used to procure this statement. The native races are usually very prone to follow the suggestions contained in leading questions, and so to give the answer desired by the questioner. To obtain an entirely independent and unguided answer is one of the most delicate of tasks. Yet their statement has some value, and combining the evidence of the physical conditions and the Indian legends, it may be said that it is probable that the lake disappeared and left the desert as we have known it in historical time, from five hundred to one thousand years ago.

THE DESERT FLOOR.

SLOPE OF FLOOR.

From this sketch of the origin of the desert it will be realized that the floor of the greater part of it for many miles north and south of the international boundary line is Colorado River delta, and that the grades of those portions of it now above the gulf level and originally above the level of Lake Cahuilla^a are the grades that would be established by a river of the type of the Colorado, carrying the burden of silt which it carries, and are fairly uniform. The peculiar and—from the engineer's point of view—the most significant feature about the desert surface, however, is the steep grade of its northern slope from the old water line in the vicinity of the international boundary to the bottom of the Salton Sink.

From Yuma to the gulf, a distance of about 80 miles, there is a fall of 142 feet, uniformly distributed, while from Yuma to the bottom of the Salton depression is approximately 120 miles and the fall about 416 feet, but this fall is not uniformly distributed (Pl. I). The grade from Yuma to the gulf, therefore, is only about half of the average of that from Yuma to Salton, and throughout a part of the latter distance the difference is even greater; for example, from Sharps heading to the -250-foot contour north of Brawley the distance is

^aThe writer had proposed to call the ancient water body of which the Salton Sea is the successor "Blakes Sea," after Prof. Wm. P. Blake, who, as a result of his exploration of the Colorado Desert in 1853, explained so clearly and so satisfactorily the phenomena that exist there and their origin. The manuscript of this report was prepared in accordance with this intention, but before it was published Professor Blake had himself proposed the name Lake Cahuilla (*Nat. Geog. Mag.*, vol. IV, p. 830). While I regret that the name of this honored pioneer in western geology can not be attached to one of his most striking discoveries, I realize that no other man has an equal right to name the now vanished water body, that the name is especially appropriate, and that it now has priority; therefore it is adopted here.



THE OLD WATER LINE AND THE NEW LAKE ABOVE FISH SPRINGS.

not over 50 miles and the fall is about 280 feet, or more than three times that from Yuma to the gulf.

This steep and irregular character of the northwest slope of the Colorado delta, as compared with its flat and relatively uniform south-east slope toward the gulf, is due entirely to the fact that the latter slope represents a stream grade determined under usual conditions, whereas the former is determined in part by the deposition of the silt in the still water of the lake that once existed there. The two slopes are therefore of entirely different origin and, of course, are of different grade.

This fact bears in two important ways on the problem of conducting Colorado River waters to the Imperial Valley for irrigation. In the first place it makes it easy to lead the waters in this direction, as it would not be were the grade no steeper toward the sink than toward the gulf; and in the second place it introduces an element of danger, because the northwestern course is so much more favorable than that toward the southwest, and it is always possible that during floods the stream may abandon its course to the gulf and adopt a new and more favorable one toward the sink. These possibilities and this danger have been illustrated in a startling way by the spectacular events of the last few years in the Imperial Valley.

DEVELOPMENT OF IMPERIAL CANAL SYSTEM.

In April, 1896, the California Development Company was organized by S. W. Ferguson, J. H. Beatty, H. Heber, and C. R. Rockwood to conduct water from Colorado River, at a point about $1\frac{1}{4}$ miles above the location since chosen for the site of the cement headgate to a point 14 miles away, on the Mexican side of the international boundary, where the channel of the Alamo was sufficiently well-defined to serve as a canal. It was planned to conduct the water along this channel through Mexican territory to the international boundary again 7 miles east of where Calexico now stands, and there to distribute it by means of a system of canals over lands in the United States.

Actual construction of the canal was begun about 100 yards above the international boundary in 1900, and was carried through to Calexico in June, 1901, when water was first delivered and irrigation begun. C. R. Rockwood, long a high officer in the company, estimates that there may have been 1,500 or 2,000 people in the Imperial Valley at that time, a large proportion of them in the employ of the California Development Company.

For three or four years after the first delivery of water to the lands colonization was rapid, the agricultural areas were extended, and what had been regarded as worthless desert was gradually reclaimed.

The fields of grain and alfalfa and the rows of trees, principally cottonwoods, which were planted completely altered the appearance of the country

INFLOW OF THE COLORADO.

During each low-water period after the completion of the canal some difficulty was encountered in getting water to flow freely through the canal just below the intake because of the silt that accumulated there. As the demand for water became greater with the increasing acreage under irrigation this difficulty was increased, and it was found necessary to cut, first a by-pass around the headgate at the intake, and then new intakes lower down, the dredges at hand being unable to keep the upper end of the original canal free from silt. It was intended that these additional cuts should be kept open only temporarily, in order to keep up the supply of water during the low-water period.

In October, 1904, the lowest intake, known as No. 3, was cut, in order to avoid a shortage of water during the period of low flow then on. Attempts were made to close it early in 1905, but high waters swept away the dams that were built, and the flood period of 1905 approached with this third intake still open. During this flood period the intake and the canal were greatly enlarged by the tremendous volume of Colorado River waters which flowed through the opening, and by the time the summer floods had subsided the entire Colorado had abandoned its normal channel to the gulf and was flowing westward and northward to Salton Sink by way of the channels of its old distributaries, Alamo and New rivers.

During this period the lake in the Salton depression grew rapidly, and the Southern Pacific Company was forced to build a succession of "shoo-fly" tracks, each higher than the last, in order to keep above the advancing waters and prevent interruption to traffic on its main line. The floods, too, had accomplished extensive destruction in the Imperial Valley, drowning many acres of valuable lands and destroying canals and farms near the flood channels (Pl. VI). It was realized, therefore, that the situation was grave, and preparations were made on a more extensive scale to control the river when the summer floods of 1905 should have passed.

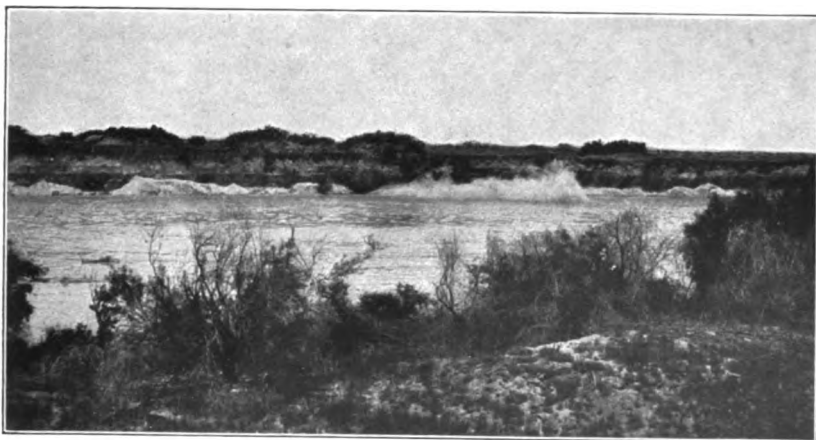
A brush mat and piling dam, known as the Edinger dam, was begun in the autumn of 1905, but was swept away by the flood of November 30. An attempt was then made to extend a dam from an island opposite the intake to the west bank of the river, but high water swept this work away too. Constantly recurring floods during the spring of 1906 foiled all efforts to redirect the river, and during that period and the period of the summer floods the channels to the



A. NEW RIVER IN FLOOD NEAR THE FIVE HEADINGS.



B. A CHARACTERISTIC RECENT DRY ARROYO IN THE DESERT.



C. NEW RIVER IN FLOOD, NORTHWEST OF IMPERIAL, SUMMER OF 1905.

Salton Sink were deepened and widened, the destruction within the Imperial Valley was extended, and the lake grew and forced the Southern Pacific to rebuild at higher and higher levels.

When the summer of 1906 had passed with the river still beyond control, the California Development Company had reached the end of its financial resources, and all growth in the valley had ceased because of world-wide recognition of the menace to property interests which the uncontrolled condition of the Colorado meant. It was then felt that the only powers at hand capable of dealing with the situation were the Southern Pacific Railroad and the United States Government. The Southern Pacific made loans to the California Development Company to carry on its fight against the stream, and by means of its transportation facilities rendered additional essential aid. After the passage of the summer floods of 1906, the first attempt to control the river was the completion of the Rockwood gate, work upon which was begun the year before, but suspended in order that the plan realized in the building of the Edinger dam might be tried. With the failure of the Edinger dam and the approach of low water in the fall of 1906, the Rockwood gate was completed, but this, too, was carried out in the flood of October 11, 1906. A spur track was then built from the main Southern Pacific line at Hanlon Junction down the Colorado past the base of Pilot Knob; a trestle was built across the canal, which long since had been enlarged to the size of the original Colorado channel, and an attempt was made to check the stream by dumping into it, from flat cars, broken rock drawn from all the available quarries along the Southern Pacific line within several hundred miles. At the same time earth dikes were built parallel to the river for a number of miles above and below the dam, which came to be known as the Hind dam, in order to prevent the river from cutting around the structure when completed.

This effort was successful in November, 1906. The stream was turned from its course to the Salton Sea and forced into its old channel to the gulf, and it seemed that the end sought had at last been accomplished.

But on December 7, during a moderate flood following the closure, a breach was effected in the levee 2,500 feet below the dam, and in a short time this break had deepened and widened until the whole stream was again turned toward the sink.

The people of the Imperial Valley, the engineers in charge of the work, and the Southern Pacific officials whose immediate and prospective interests were seriously menaced were deeply discouraged by this turn in affairs. Money and effort had been freely expended. The struggle, at times apparently hopeless, had been long continued, and the longer the stream flowed toward the desert the more difficult

the problem became of controlling it, because, the grade toward the sink being approximately two and one-half times that toward the gulf, there was a well-marked tendency to scour out the bottom of the channel and thus to cut the new bed below the old one. This tendency was expressed in a most spectacular way by the extension through Calexico in July, 1906, of a fall of 40 feet or more in New River. This fall retreated upstream at an alarming rate, and at one time there was a serious and well-grounded fear that the entire canal system of the Imperial Valley would be left without a water supply by its extension to the Alamo channel above Sharps heading. In a final readjustment of grades by the river it was evident that the channel would be greatly deepened for many miles above Yuma, the Government dam at Laguna rendered impossible, and all agricultural interests along the lower course of the river destroyed, because the grade of the river would be lowered far below the canal intakes.

In the face of the repeated failures, the Southern Pacific seemed ready to abandon its attempt to close the canal, and appeal was made to the Government. The matter soon attracted national attention. An extensive correspondence was carried on between the President and Mr. E. H. Harriman, president of the Southern Pacific Company, and a special message dealing with the problem was sent to Congress. The Government had neither available funds, proper authority (the break was in Mexican territory), nor the equipment at hand for the prompt and vigorous action that was necessary to control the situation, and the railroad company, which had all of these, finally again undertook the work, the Government lending its engineers for consultation. The levee was practically reconstructed, broadened, made higher and extended downstream, and the same method was used to close the actual break that had proved successful when the Hind dam was built. Work was begun on this last project December 20, 1906, and the closure was completed February 11, 1907. Since then the work has withstood two summer seasons of high water, and there seems no reason why it should not prove permanent.

To safeguard the valley finally and completely, however, and to insure for it a regular water supply, further extensions of the levee system are necessary, and a more satisfactory method of dealing with the silt that the river carries must be worked out.

THE VALLEY DEPOSITS.

Classification of materials.—The evolution of the desert having been sketched and some of the events which are directly dependent upon its character as determined by that evolution having been pointed out, the nature of the materials which underlie it and the bearing of their character upon the problem of the occurrence of ground waters

may now be considered. The four classes of materials that make the floor of the desert valley in different parts are the delta silts, the consolidated clays and sandstones, the stream-deposited alluvium, and the wind-blown sands. A fifth class of deposit, of very small mass but of some commercial value—the saline deposits of the Salton marsh—should also be mentioned.

Delta silts.—The most important of these in mass is the body of silts and fine sands supplied by the Colorado and making up the whole of the delta lands, the greater part of the southern end of the Salton basin, and an important share of the northern end of the basin. Presumably the larger part of the total volume of these fine silts was deposited in still water, the gulf or the old lake. An important part, however, represents alluvial deposit from the overflow of the river waters. So fine are all of the materials that no important difference exists between those deposited in the gulf or the lake and those representing overflow or flood-plain deposits. They are all so fine grained as to be nearly impervious; that is, the pore spaces are so small that water circulates through them with extreme slowness. Their chief function in ground-water problems, therefore, is to serve as a barrier to percolation. Furthermore, within the delta proper they contain a notable amount of salts, so that the few springs which issue from them along the channels of New and Alamo rivers yield salty water, and the few experimental wells that have been put down in the Imperial Valley are dry or yield only a very small amount of salt water.

In the northern narrower end of the desert about Indio, Coachella, and Mecca, the material that fills the valley does not consist wholly of silts supplied by the Colorado, but of these intermingled with alluvium brought down by the intermittent streams from the surrounding mountains. The lake silts, or Colorado River silts, when thus interbedded with the coarser local material, perform the function of impervious confining strata, beneath which circulating waters accumulate under pressure. They are therefore important in bringing about the artesian conditions that prevail in this vicinity.

Consolidated Tertiary beds.—The floor of the west side of the valley from Signal Mountain northwestward to the base of the Santa Rosa Mountains is made up of Tertiary sandstones and clay beds, usually folded and in some places veneered with a covering of waste—sandy and gravelly alluvium. Near the valley axis, and especially below the old beach line, these beds are generally deeply buried beneath the valley filling, but toward the borders of the valley they stand higher and at many places they have been cut by erosion into fantastic bad-land forms. About ten years ago there was some excitement about oil in this region and a number of wells were drilled. These did not yield oil, but they served to test underground conditions.

The Yuha well, 6 miles north of the Mexican line and about 25 miles west of Calexico, was bored to a depth of about 1,200 feet. Salt water was found but no oil. Other wells like the Barrett, in Carrizo Creek valley, and the Hanna, at the north base of the Fish Creek Mountains, are dry holes, or obtained only salt water in the Tertiary beds. The Harper well, however, in the San Felipe Wash, at a reported depth of about 300 feet struck potable artesian water in the valley alluvium that overlies the Tertiary rocks.

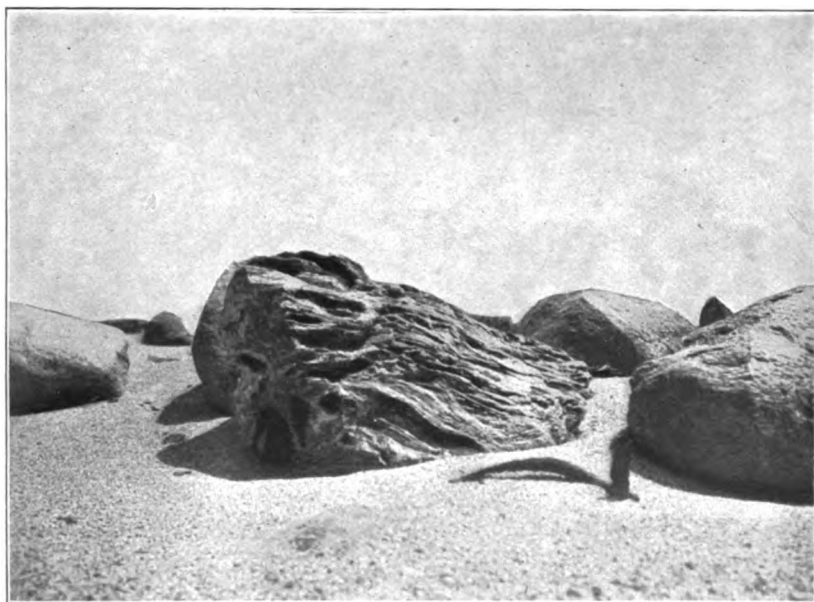
Along the eastern border of the valley, as along the western, there is a fringe of Tertiary rocks, somewhat more extensively folded, as a rule, than those on the west, but bearing the same general relation to the valley. No wells have been drilled in these rocks so far as is known, but their character is such that waters of good quality need not be expected from them, although flowing waters might be obtained in some of the synclines. In the vicinity of Durmid, Bertram, Frink, and Imperial Junction these beds have been planed off and form a portion of the smooth, sloping, desert floor below the old beach line. Generally, however, along this eastern margin of the desert they are deeply eroded and form rough foothills along the base of the higher mountains to the east.

Sand dunes.—At certain seasons of the year strong winds blow toward the desert from San Gorgonio Pass and the mountains on either side of it. As these winds sweep down into the upper end of the desert they sift the sands from the alluvial material brought from the basins of the Whitewater, Mission Creek, Palm Canyon, and other streams, and carry them farther out into the desert basin. In this vicinity the effectiveness of the wind as a transporting agent is enormous. Professor Blake observed the effects of wind erosion here and figured examples of dense and resistant rocks deeply etched by the sand blast (Pl. VII, *B*). Since the Southern Pacific Railroad was built many other proofs of this action may be seen (Pl. VII, *A*). For example, the telegraph poles are worn away near the ground and have to be protected there by posts or rock piles. The more resistant knots or growth rings are brought into high relief by the etching of softer parts. The fish plates and bolts of the railway tracks are eroded rapidly, and the tin cans strewn along the track are kept bright and polished by the driving sand and are quickly etched through, as by acid, and worn away.

In the neighborhood of Indian Well there is a belt of sand dunes several miles long, but generally in this north end of the desert the phenomena are those of rapid removal rather than of even temporary accumulation as in dunes. As a result the desert floor is a sandy, rocky waste, with scant vegetation, and the air is full of dust, sand, and fine pebbles whenever the wind blows. But a very extensive sand dune area exists in the southeastern portion of the desert.



**A. TELEGRAPH POLE NEAR PALM SPRINGS STATION
DEEPLY CUT BY WIND-BLOWN SAND.**



B. BOWLDER OF GNEISS NEAR PALM SPRINGS STATION, ETCHED BY WIND-BLOWN SAND.

From the vicinity of Mammoth station to a point a few miles south of the Mexican line, a distance of 40 or 50 miles, there is a continuous belt of dunes (Pl. VIII), from 2 to 6 or 8 miles wide.

An approaching sand storm in this region may always be seen while it is yet a long distance off, because the air is filled with dust to a height of several hundred feet. An estimate of the amount of material moved at such a time would be interesting, and though exact figures can not be obtained suggestive estimates are possible.

Saline deposits.—The bottom of the Salton depression before it was covered with water as a result of the inflow of the Colorado River was a salt-incrusted marsh. Within certain sections the salt crust was 6 inches or 1 foot thick, and sufficiently pure to permit it to be gathered in a commercial way and marketed at a good profit. The New Liverpool Salt Company undertook the commercial development of this marsh in the early eighties, and a profitable industry had been established when the inflow of water in 1904 put a stop to the work. In mining the salt the crust was removed and purified, and after a time was found to have been renewed.

The New Liverpool Salt Company sunk a well to a depth of somewhat more than 700 feet, and obtained flowing water under a pressure of 48 pounds per square inch. This water contained 1 per cent saline matter, thus proving the existence of salts at great depth in this depression. The managers of the salt company report that there is always water at or just below the level of the crust, and this in spite of the rapid evaporation there during the summer. Mr. Durbrow, for a number of years manager of the salt company, has testified to maximum evaporations of as much as $\frac{1}{8}$ inch in twenty-four hours in shallow pans during a period when maximum temperatures of 140° were reached. The water thus constantly carried into the air by evaporation must be replaced from underground sources, because surface inflow normally is slight and comes at very irregular intervals. The artesian pressures proved by the drilling of the salt company's well, by the numerous flowing wells farther north in the desert, and by the springs at Figtree John's, Alamo Bonito, and Agua Dulce, indicate that there is constant seepage toward the surface. The bottom of the sink has been an evaporating pan for a long period. From the time when this depression was first separated from the gulf by the extension of the delta dam from Yuma to the Cocopas, it has probably been filled by inflow from the Colorado and emptied by evaporation many times. During all of this time, also, it has been shoaling slowly because of accumulating wash and silt. Whenever the depression has been occupied by a lake, more or less silt has been deposited from the waters. In dry periods occasional heavy rain storms in the desert result in an inwash of materials from its borders. The muds thus deposited in

the bottom of the sink have contained definite though minute quantities of salts, and thus saline matter has accumulated there.

Probably the most abundant source of salts is the underground water that percolates slowly toward the basin from the northwest. This is of exceptional purity, as is shown by analyses of water from wells at Indio and Coachella, but like all natural waters it contains a small percentage of salts, and all of this is left behind as the water evaporates from the surface of the salina.

Since the ground waters rise at other points than in the very bottom of the valley, salts are found at the surface in many areas outside the Salton Sink. Indeed, wherever the ground-water level is so near the surface that the processes of evaporation and capillarity are sufficiently powerful to draw them quite to the surface, alkalies will inevitably accumulate, their amount depending on the rapidity of the process. When salts have accumulated at the surface all storms of sufficient magnitude to give surface streams into the sink carry a portion of these salts with them and assist in their concentration there.

WATER RESOURCES.

RAINFALL AND DRAINAGE.

The region north and east of Indio has not been mapped with sufficient accuracy to enable us to make a close estimate of the drainage area tributary to the Coachella valley; but a rough estimate, based on fairly accurate maps of the south and west limits of the valley and on much less accurate data in other directions leads to the conclusion that the drainage basins whose surplus waters escape to the Salton Sea from the northwest have a combined area of about 2,000 square miles. Probably 20 per cent of this total has a rainfall of from 5 to 25 inches per annum. The following tables comprise records of rainfall at Palm Springs (1889-1905), Indio (1878-1905), and Yuma, Ariz. (1884-1905):



EASTERN BORDER OF SAND DUNE AREA WEST OF MAMMOTH STATION.

Rainfall records.

AT PALM SPRINGS, CAL.

Year.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	Rainfall for season.
1889-90	0.00	0.07	0.00	0.53	0.00	4.64	.52	0.06	1.54	0.00	0.01	0.00	1.91
1890-91	0.00	.25	.38	.00	.00	.60	.00	7.44	.00	.00	.00	.00	5.86
1891-92	.03	1.02	.10	.00	.00	.23	2.18	.28	.05	.00	.12	.00	8.57
1892-93	.00	.00	.00	.00	.00	.00	.40	.00	1.18	.00	.10	.00	3.99
1893-94	.35	.40	.10	.00	3.00	.11	.00	.00	.00	.00	.00	.00	1.68
1894-95	.00	.00	.00	.00	.00	4.25	3.50	.00	.00	.00	.00	.00	3.96
1895-96	.00	.00	.00	.00	.00	3.50	.00	.00	.81	.03	.00	.00	7.75
1896-97	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	4.34
1897-98	.00	.00	.00	.00	.00	1.09	.00	.00	.60	.00	T.	.00	.00
1898-99	.00	.00	.00	.00	.00	.70	1.21	.12	.00	.00	.00	.00	1.69
1899-1900	.00	.62	T.	.00	.50	2.86	.80	.00	.00	.00	.00	.00	2.03
1900-1901	T.	.00	.00	1.29	T.	.00	T.	3.50	.00	.00	.00	.00	4.78
1901-2	.00	.00	.00	.00	.00	.00	.50	.00	.50	.50	.00	.00	4.79
1902-3	.00	.00	.00	.00	.70	.70	.00	.00	.70	.00	.00	.00	1.50
1903-4	.00	.00	.00	.00	.00	.00	T.	T.	.00	.00	.00	.00	2.10
1904-5	.00	1.00	.00	.10	T.	.00	2.16	3.95	1.66	T.	.48	.00	T.

Average for 16 years, 3.90 inches.

AT INDIO, CAL.

1878							0.10	0.00	0.00	0.00	0.00	0.00	0.10
1878-79	0.00	0.00	0.00	0.00	0.00	1.00	.60	.30	.00	.00	.00	.00	1.90
1879-80	.00	.00	.00	.00	.40	.00	.00	.00	.00	.00	.00	.00	.40
1880-81	.00	.00	.00	.00	.00	.70	3.45	.00	.50	.00	.00	.00	4.65
1881-82	.00	.00	.00	.00	.00	.00	1.50	.00	.00	.00	.00	.00	1.50
1882-83	.00	.00	.00	.00	1.00	.00	.80	1.13	.11	.00	.00	.00	2.43
1883-84	.00	.00	.00	.06	.00	.86	.00	3.16	.62	.44	.46	.00	5.60
1884-85	.00	.00	.00	.00	.00	.70	.00	.00	.00	.10	.00	.00	.80
1885-86	.00	.00	.00	.00	.90	.00	.00	.00	.00	.00	.00	.00	1.90
1886-87	.00	.00	.00	.00	.12	.00	.00	.93	.00	.30	.00	.00	1.35
1887-88	.00	T.	.05	.15	.00	.00	.75	.00	.00	.00	.00	.00	.95
1888-89	.00	.00	.00	.00	1.10	1.11	.57	.00	1.05	.00	.00	.00	3.83
1889-90	.00	.95	.00	.60	.01	3.29	.65	.06	.00	.00	.00	.00	5.56
1890-91	.00	.10	.20	.00	.00	.22	.00	1.90	.00	.00	.00	.00	2.42
1891-92	.00	1.16	.00	.00	.00	.25	2.00	.43	.22	.04	.14	.00	4.24
1892-93	.00	.00	.00	.00	.00	.00	.03	.00	1.60	.00	.00	.00	1.63
1893-94	.05	.75	.07	.00	.14	T.	.00	.00	.00	.00	.00	.00	1.01
1894-95	T.	.00	.00	.00	.00	.00	6.01	.00	.00	.00	.00	T.	6.01
1895-96	.00	.00	.00	.00	.00	.00	.92	.00	.00	.00	.00	.00	.92
1896-97	.00	.00	.00	.00	.00	.00	1.10	.19	.00	.00	.00	.00	1.29
1897-98	.00	.00	2.10	.00	.00	.00	.10	.00	.30	.00	.00	.00	2.50
1898-99	.00	.30	.00	.00	.00	1.00	.40	.00	.00	.00	.00	.00	1.70
1899-1900	.00	.00	.10	.00	.60	.20	1.00	.00	.30	.15	T.	.00	2.35
1900-1901	.00	.00	.08	1.04	.17	.00	.29	1.46	.00	.00	.00	.00	3.04
1901-2	.00	.00	.00	.00	.00	.40	.20	.00	.00	.00	.00	.00	.60
1902-3	.10	.00	.00	.00	.50	.80	.00	.00	.00	.75	.00	.00	2.15
1903-4	.00	.10	.12	.00	.00	.00	.00	.00	.00	T.	.00	.00	.22
1904-5	.00	.33	.00	.00	.00	.00	2.16	3.95	1.66	T.	.48	.00	8.58

Average for 25 years, 2.65 inches.

* Broken record.

AT YUMA, ARIZ.

1884							T.	1.58	1.48	0.07	0.44	T.	3.57
1884-85	0.01	0.32	T.	T.	T.	1.96	.02	.08	.33	.07	.31	.00	2.38
1885-86	.05	.86	0.00	0.00	1.71	.01	1.06	.08	.33	.31	.00	.00	4.41
1886-87	T.	2.23	.00	1.11	.23	.00	.00	T.	.00	.20	T.	.01	3.78
1887-88	T.	T.	1.09	.02	2.43	.15	.18	.05	.05	T.	.00	.00	3.97
1888-89	.04	T.	.01	.99	.68	.95	1.12	.06	.24	.00	.00	T.	4.09
1889-90	T.	.25	.00	.59	T.	2.43	.08	.11	.06	.53	T.	.00	4.05
1890-91	.02	T.	.00	T.	T.	.00	.00	2.53	T.	.00	T.	.00	2.55
1891-92	.04	.05	T.	.00	.00	.05	1.85	.87	.52	T.	.05	.00	3.43
1892-93	.00	.02	.04	.00	.00	T.	T.	.00	1.53	.00	.31	.00	1.90
1893-94	.40	.42	.30	.00	.30	.11	.00	.00	.00	.00	T.	.00	1.53
1894-95	.30	.01	.12	1.25	.00	.29	.78	.02	T.	.00	.00	T.	2.77
1895-96	.01	T.	T.	.15	.37	.00	.14	.00	.43	T.	T.	.00	1.10
1896-97	.41	.32	.31	.10	.06	.78	2.83	.06	.48	T.	T.	.00	5.35
1897-98	T.	.57	.20	T.	.00	.04	.42	.00	.39	.01	.00	T.	1.63
1898-99	.00	.19	.00	.00	.21	1.16	.00	.01	T.	.00	T.	T.	1.57
1899-1900	T.	.06	.00	.02	.50	.00	.08	.11	.06	.53	T.	.00	1.36
1900-1901	.02	T.	.00	(?)	T.	.00	.12	3.01	.30	T.	T.	.00	3.45
1901-2	T.	.22	.00	T.	.00	.00	.26	T.	.21	.00	.00	T.	.69
1902-3	.11	T.	T.	.00	.57	.78	T.	.23	T.	T.	.00	.00	1.69
1903-4	.04	T.	.67	.04	.00	T.	.00	T.	.28	T.	.07	.00	1.10
1904-5	.05	.69	.24	T.	.00	.10	1.15	3.43	3.33	.16	.00	.00	9.15

Average for 21 years, 2.95 inches.

The more effective portion of the tributary drainage area includes the eastern slope of San Jacinto Peak and the southern and eastern slopes of the San Gorgonio Mountain mass. From these mountains small perennial streams flow into the northern end of the desert. The largest of these is Whitewater River, which rises on the eastern slopes of San Gorgonio Peak. At the foot of San Gorgonio Pass its waters are divided, one portion being utilized for irrigation in the vicinity of Whitewater station, while another portion, at one time used for irrigation at Palm Springs, is allowed to waste into the desert.

From Palm Canyon also a perennial stream flows, and Tahquitz Creek and other minor streams which rise on San Jacinto Peak furnish small amounts of water to the neighboring portions of the desert.

Over the remaining 80 per cent of the desert ranges whose slopes are in the direction of the Coachella Valley, the precipitation is extremely meager. At Indio it averages about 2.65 inches per year, and is probably but little more on the desert ranges to the east. A somewhat larger amount, which increases with the altitude, falls on the northern slopes of the Santa Rosa Mountains, because these are higher and receive some share of the moisture that is borne eastward by the Pacific winds.

Much of the rainfall in the desert comes in heavy storms of short duration, and since the slopes on which it falls are free from vegetation and have but little soil covering, the proportion of run-off is large—much larger than in more humid and better forested areas. But as the desert air is intensely dry, the immediate loss by evaporation must be a large proportion of the total fall.

At the base of each mountain range, where great alluvial fans containing much coarse material are piled up, such flood waters as reach them are promptly absorbed. Hence, in spite of the intense heat of the long summer, and the unfavorable situation of the valley in regard to rainfall, the large tributary drainage area must result in a considerable aggregate annual contribution to the underground supply. It is not possible, however, to make any definite estimate of its amount.

East and west of the southern end of the desert—the Imperial Valley—are arid ranges like those that inclose the Coachella Valley, except that they are not so high and not so effective as rain makers. Furthermore, this south end of the desert is much wider than its northern end, and the very slight and uncertain run-off from its bordering mountains does not reach the heart of the basin. On the other hand, a portion of the overflow from the annual summer floods of the Colorado occasionally extended down into the valley before irrigation began there. Sloughs of fresh water were thus occasionally

found along the channels of New and Alamo rivers, and intermittent water basins like Cameron Lake, Blue Lake, and Mesquite Lake were sometimes filled by these flood waters. Farther south, in Mexico, in the vicinity of Volcano Lake, which is near the divide between the Salton Basin and the Gulf of California, flooding during the summer high-water period in the Colorado is usual instead of rare. Indeed, this part of the desert, which for years has been used as a cattle range, owes all of its value for this purpose to the natural irrigation that it receives during the summer floods in the river.

UNDERGROUND WATERS.

LIMITS OF ORIGIN.

The geologic conditions within and about the borders of the desert preclude the possibility of its ground waters originating in drainage basins beyond the surrounding mountains. These ranges are formed of granitic and metamorphic rocks, practically impervious to water, 50 or 100 miles through, and extending indefinitely downward. It is impossible to conceive that water circulates through them in any valuable quantity. It has also been suggested that these waters may be derived from Colorado River, not by percolation through the separating mountain ranges but by subsurface flow around the southern point of these ranges through the sands and silts of the valley.

A consideration of the distribution of temperatures and of the character of the waters over the Coachella Valley is sufficient to show that the supply does not come from the southeast. The average temperature of well waters near the northwest end of the area in which developments have taken place is about equal to the mean annual temperature of the region—72°. Nearer the Salton Sink the temperatures of waters are higher. Here the springs or shallower wells have temperatures of 75°, 80°, and 90°.

An experimental well has been sunk in the very bottom of the Salton basin by the company that mined salt there before the inundation, and a flow of water with 1 per cent saline matter and a temperature of 92° was obtained at a depth of 500 feet.

Other saline and sulphuretted waters were found in wells, now submerged, in the vicinity of Mortmere, and the springs southeast of Figtree John's are saline, sulphuretted, or carbonated.

Below the Salton Basin, 5 or 6 miles south of Lano station, in an area now submerged, there was a group of boiling mud springs. The waters that rose here were not potable; some were acidulated and some had temperatures of 212°. Furthermore, in the vicinity there are the remnants of old volcanoes. It is wholly unlikely that Colorado River waters percolate eastward through areas in which highly mineralized and highly heated waters of the types just mentioned exist. This is particularly true because the normal waters of Indio and vicinity are of great purity. That they contain but 15 to 25

parts of solid matter per 100,000 parts of water is shown by the following analyses:

Analyses of Colorado desert waters.

[Analysts, G. E. Colby and M. E. Jaffa, University of California.]

[Parts per 100,000.]

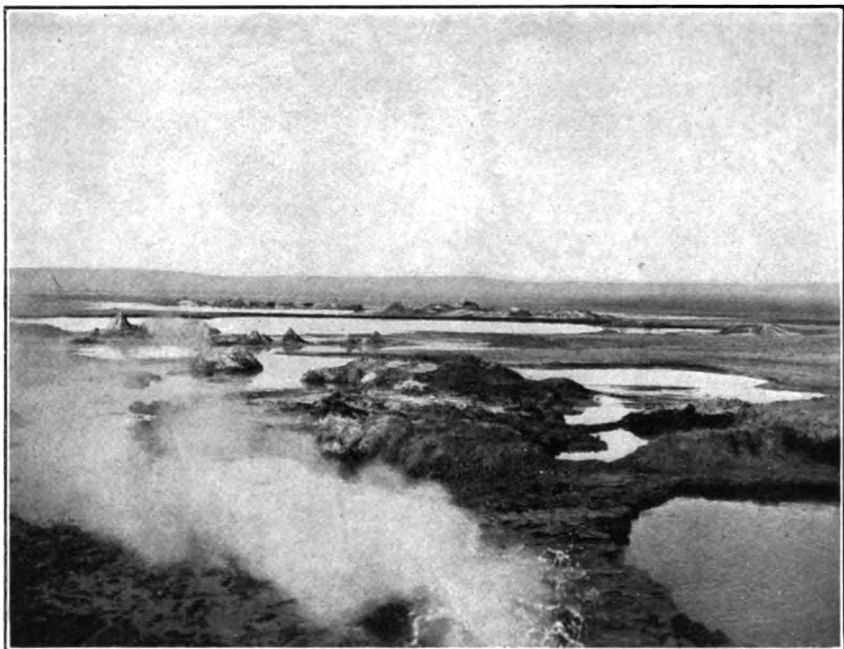
	1. From sur- face-water well 20 feet deep, one-half mile northeast of Indio station.	2. From water strata 120 feet deep, one-half mile northeast of Indio.	3. From reservoir at Coa- chella.	4. From artesian strata 500 feet deep at Coachella.	5. From sur- face well 25 feet deep, one-half mile north of Coachella.
Sodium and potassium sulphates, etc.....	4.3	4.3	4.92	6.3	3.4
Sodium chloride (common salt).....	1.12	.20	.18	.20	.20
Sodium carbonate (sal soda).....	2.1	2.10	6.40	4.30	1.50
Calcium and magnesium carbonates, etc.....	7.0	6.8	1.10	3.00	7.4
Calcium sulphate (gypsum).....	4.0	4.0	1.00	1.00	2.00
Silica.....	.40	.40	1.40	1.12	0.9
Organic matter and chemically combined water.....					
	18.00	17.8	15.00	16.00	25.50

All the water clear, colorless, odorless, and tasteless.

An additional proof of the dependence of the Indio underground supply upon local rainfall was furnished by the prompt response of the wells to the exceptional rainfall in the winter of 1904-5. Wells whose yield had been noticeably affected by the developments of the preceding four years were restored to approximately their original flow by that seasons's rains. Such a response could not occur if the Colorado River were the source of the waters.

These arguments add strength to the inherent improbability, amounting practically to a certainty, that waters in any valuable quantity percolate through the 100 miles or more of close-textured Colorado River silts that lie between Yuma and Indio. It must therefore be concluded that these waters enter through the alluvial material that occupies the borders of the valley, especially near its northern end, where the water supply is greatest, and move thence slowly toward the center of the basin. It is these waters in slow motion toward the Salton Sink that are intercepted by the 400 wells of the Coachella Valley.

The physical conditions which control the movements of the underground waters may be readily inferred from the character of the deposits that fill the valley. Except about the borders these deposits are fine. This follows directly from the fact that they are in part lake sediments and in part the outer edges of alluvial fans. Well drillers in the valley are able to sink wells to depths of 600 or 800 feet by the hydraulic method, which can be used only where no coarse material is encountered (fig. 2). The strata which they pierce are alternating layers of clay and sand with occasional streaks of very fine gravel. This alternation of fine and coarse material (fig. 3), which is essential to artesian conditions, exists presumably only in the northern end of the desert. Few boulders are encountered (fig. 4), and these are about the borders of the



A. GROUP OF ACTIVE MUD VOLCANOES WEST OF IMPERIAL JUNCTION.



B. GENERAL VIEW OF QUIESCENT MUD VOLCANOES NEAR IMPERIAL JUNCTION.

basin, where their source may usually be recognized in a near-by canyon. South of Salton Sink, where the original lake was larger and the material with which it was filled was supplied more directly

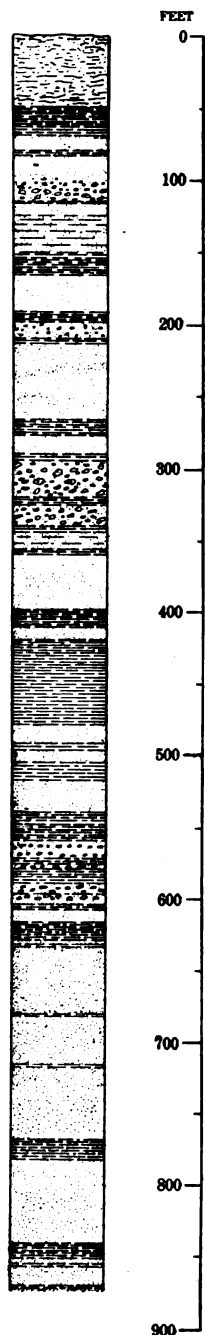


FIG. 2.—Section of Southern Pacific well at Indio, Cal.

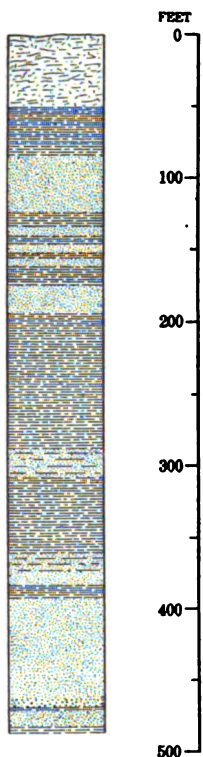


FIG. 3.—Section of Southern Pacific well at Mecca, Cal.

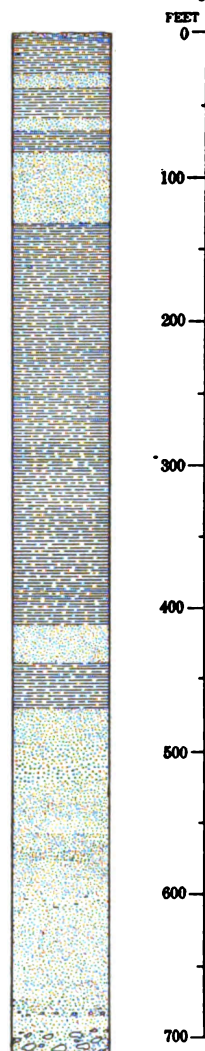


FIG. 4.—Section of Southern Pacific well at Mortimore, Cal.

by the distant Colorado River, the coarser strata are much more rare. Drill records here reveal a comparatively uniform series of fine sediments through which the circulation of waters in sufficient amounts to give artesian pressures is scarcely possible. Two or three deep wells have been drilled near Imperial, but no flow was obtained, and the water found in limited quantity was too saline to be usable. The northern limit of these nonartesian conditions can not be predicted closely. North of the southern end of the old Salton marsh, however, flowing waters will be found, although for a number of miles they will not be suitable either for drinking purposes or for irrigation; but south of this limit artesian waters of any quality need not be expected, except perhaps in small areas near the mouths of the larger canyons where local conditions may be favorable. The Harper well, near the San Felipe wash, drilled for oil but yielding flowing water, is a case in point.

A matter of more importance to the irrigator than the theoretical limits of the artesian basin is the limit of the usable waters. This can not be determined theoretically; but the waters developed by wells drilled near the old Mortmere switch, and the position and character of some of the natural springs, indicate that ground waters sufficiently pure and in sufficient quantity to be used for irrigation may be found northwest of a line crossing the valley from the southern end of the Santa Rosa Mountains to the vicinity of Salton Station; southeast of this line the waters are distinctly saline. The heavy incrustations of surface alkalis which occupy the center of the valley for a number of miles northwest of this limit of usable waters, and preclude the use of the land for agricultural purposes, will probably be more potent than the character of the waters in checking development toward the southeast.

SOURCE AND CHARACTER OF THE UNDERGROUND SUPPLY.

The only source of the underground waters of this region is the rainfall on the desert and the surrounding mountains. It has frequently been suggested that distant and less obvious sources might supply the waters that seem to irrigators within the Coachella Valley too abundant to be due entirely to run-off from the desert ranges about them. A similar opinion is commonly held in artesian areas, because proper value is not given to the importance of the time element in the accumulation of underground waters. The waters that are being developed in the Coachella Valley have slowly accumulated there throughout a long period. The amount annually added to them is but a small percentage of the total supply. Before irrigation was begun this annual increment served simply to balance the amount annually reaching the surface by capillarity and artesian pressure and there evaporating; for with the land surface in

the Salton Sink 273 feet below sea level, and a great body of nearly impervious silts intervening, there can be little if any escape of desert waters toward the gulf by percolation. Irrigation, through the boring of artesian wells, probably somewhat reduces this natural loss in the lowest parts of the area, because it reduces artesian pressure; but it substitutes a greater loss from the irrigated surface and from locally raised water tables.

PRESENT DEVELOPMENT AND CONTROLLING CONDITIONS.

In April, 1905, the amount of water developed by the artesian and pumped wells in the Indio basin during the irrigating season was about 100 second-feet, an amount equivalent to a continuous flow of about 20 or 25 second-feet maintained throughout the year. Impressive estimates of the total amount of water stored in the desert might be made, since it has an area of at least 400 square miles above Salton Sink and the depth of the saturated sands over this area probably averages more than 1,000 feet. Such an estimate, however, can have little value, not only because it is based upon many unknown factors, but also because the amount of water which may be taken from a basin depends not on the total amount stored there but on the amount annually added. This amount is necessarily much smaller for the desert than in the more humid area to the north, known as the valley of southern California, and even there, where the amount of water annually available for a recharge of the underground reservoirs is many times what it is in the Indio region, the artesian areas have shrunk 35 per cent in the past ten or twelve years as a result of intense development.

The effect of the development for irrigation upon the flow of the wells in the Indio region, particularly about the upper part of the basin, had been marked previous to the winter of 1904-5. The exceptional rainfall during that winter, however, amounting to 8.58 inches at Indio, where the average is but 2.65 inches, is reported by the well owners to have practically restored the yield of the wells to its original amount. A repetition of such exceptional weather conditions, however, is not to be expected often, so it is desirable to consider the usual effect of the present development.

The accompanying table has been prepared to show the actual condition of a few of the wells at two periods separated by an interval of two years. The first measurements were made in April, 1905, and the second in April, 1907. This list includes 36 wells distributed from Agua Dulce to Indio and represents therefore all parts of the basin. In nearly every well the water plane has lowered or the yield has lessened. In a few wells the change has been very slight; in others it has been marked. In some of the wells that two years ago were flowing freely the water now stands several feet below the surface.

Comparative records of wells.

Number.	Owner	April, 1905.		April, 1907.	
		Flow.	Distance to water.	Flow.	Distance to water.
		Inches.	Feet.	Inches.	Feet.
6	A. L. Gordon & Bro.	a 12			
7	J. W. Newman.	a 5			
9	S. B. Twomey.	a 15		7	
10	J. T. King.	a 15		7	
11	C. B. Bisbee.	a 8		2	
13	W. H. Mather.	a 15		a 10	
15	E. D. Morrill.	a 25		a 15	
16	do.	a 25		a 15	
17	J. K. Ross.		6		
18	do.		8		
41	N. O. Nelson.		b 16		
42	do.		b 15		
43	do.		b 14		
44	do.		b 16		
45	do.		b 18		
46	C. A. Hayott.		b 17		
50	Will Everett.		b 13		
51	do.		18		
52	do.		9		
74	Toro Indian Reserve.	a 25		20	
75	D. Bond.	a 14		13	
92	Mrs. S. A. Williams.	a 10		8	
128	F. A. Leap.	23		4	
132	R. B. Thayer.	26		7	
133	E. N. Stanley.	33		11	
144	Town of Coachella.	a 4		1	
160	Mr. Teagle.		22		
171	A. W. Haight.	5			
182	W. I. Hobbs.	21		7	
183	do.	a 8		4	
222	O. C. Eberhardt.	7		2	
223	do.	11		2	
244	Stanley and Payne.	a 7		5	
255	Martin and Moore.	11		2	
261	G. L. Keith.	20		10	
279	Peters, Evans & Gage.	8		5	

a Estimated flow.

b January 3, 1905.

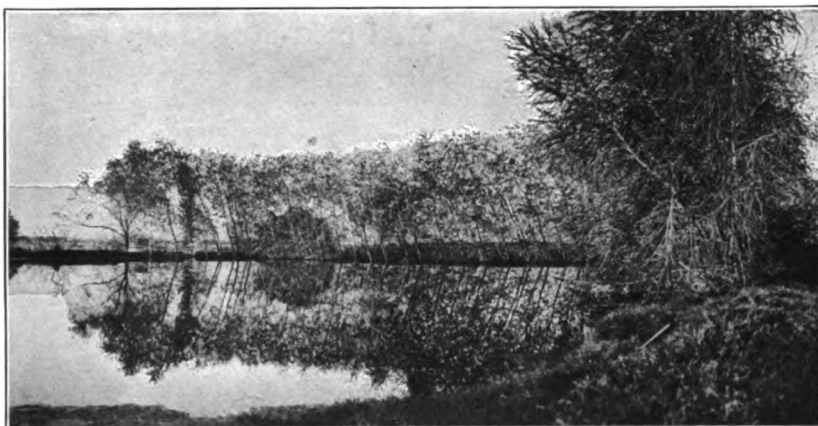
NEED OF CONSERVATION.

The continued drilling and use of wells in an artesian region diminish the area in which the wells will flow, and those about its border that are least favorably located decrease in yield or cease to flow, so that to maintain the water supply it becomes necessary to install pumping plants. This stage has already begun in the Coachella Valley, and it will undoubtedly extend over larger areas about the northern end of the artesian belt. The gravity of the condition will depend largely on the extent of future developments and on the care with which wells that are now flowing are managed. The unlimited drilling of wells in the lower, most favorably situated portions of the valley will hasten the depletion of the supplies in the higher, less favorably situated areas, and the use of pumping plants will quickly influence the yield of adjacent flowing wells.

The practice of leaving strong wells uncapped when the water is not needed can not be too strongly condemned. This waste of water not only depletes the underground reservoirs but injures the



A. A DESERT HOMESTEAD SOUTH OF INDIO.



B. EARTHEN RESERVOIR NEAR INDIO.



C. COTTONWOODS, 2 TO 4 YEARS OLD, NEAR COACHELLA, CAL.

soil over which it flows, because when the flow of water is not controlled and properly distributed the greater portion of it is evaporated from the surface, bringing about the concentration of alkali there. The greatest damage, however, results from the needless tax on the deep basins. The supply in this region will necessarily be sensitive, because the amount annually added to it by rainfall is small. A strong public sentiment, therefore, should be created, which will under all circumstances oppose the careless use of artesian wells. It should be insisted that the man who wastes or uses needlessly a product on whose abundance the prosperity of the section depends is his own and his neighbor's worst enemy. Although ranch owners generally in this section realize the need of care in this respect, there are a few important exceptions, on whom the pressure of public opinion should be brought to bear.

In addition to this obvious and useless waste there is other waste through poorly developed irrigation methods and poorly constructed reservoirs and ditches. This is a condition that is almost inevitable in new communities. Better irrigation practice comes only at a later stage, when the value of lands has been thoroughly established and agricultural habits have become fixed. It is probable that the amount of water now developed, if it could be utilized without waste, could be made to irrigate 50 to 100 per cent more land than at present.

FUTURE OF THE WATER SUPPLY.

Now, while it is obvious that additional development or even the maintenance of the present development will cause a gradual shrinkage in the artesian zone and a gradual expansion of the pumping zone—because additional development means increased drainage of the underground reservoirs by artificial means—it is nevertheless probable that the highest possible use of the underground waters will not have been reached until further developments have been carried out. There is a continuous slow movement of these subterranean waters beneath the Indio region toward the southeast, but the water does not escape to the gulf. Much the greater part of the subsurface percolation probably reaches the surface eventually in the vicinity of the Salton Sea, and before the inflow of the Colorado it escaped into the air by evaporation. A loss takes place in this manner wherever the water table stands so near the land surface that capillarity becomes effective. This condition originally prevailed over the entire area of the Salton Sink and now exists over many square miles about the lower part of the Coachella Valley above the borders of the Salton Sea. Whatever reduces artesian pressure reduces the leakage of the ground waters in this way and so decreases loss. Hence the development of artesian waters has some slight effect in lessening the proportion that is lost under natural conditions, and correspondingly increases the proportion available for man's use.

It is believed that while slow decline of artesian pressure will necessarily take place in the Indio basin, this decline need not be especially

harmful to the agricultural interests of the valley for many years to come, even although twice the amount of water now developed is procured, and it is also believed that by a proper utilization of the waters now developed and those to be developed in the future several times the acreage at present under cultivation in the valley may become productive without too great drafts on the supply.

Pumped waters will become increasingly important and will be relied upon more and more as time passes. Abundant water for pumping may be obtained at depths of 100 to 200 or 300 feet, while much deeper wells must be bored over the greater part of the area to obtain an artesian supply. Furthermore, pumped waters are used more carefully than artesian waters. Human nature can not be trusted to value or to manage well that which costs little. Therefore, artesian waters will be wasted and pumped waters will be used with care in the same area. The cheapness of gasoline and crude oil and the efficiency of engines that utilize these fuels will make their application in irrigation more and more feasible as development continues.

EFFECT OF THE FILLING OF THE SALTON BASIN.

When development began in the Coachella Valley the bottom of the Salton Sink was a salt marsh—a huge evaporating pan from whose surface many thousands of tons of water must have passed

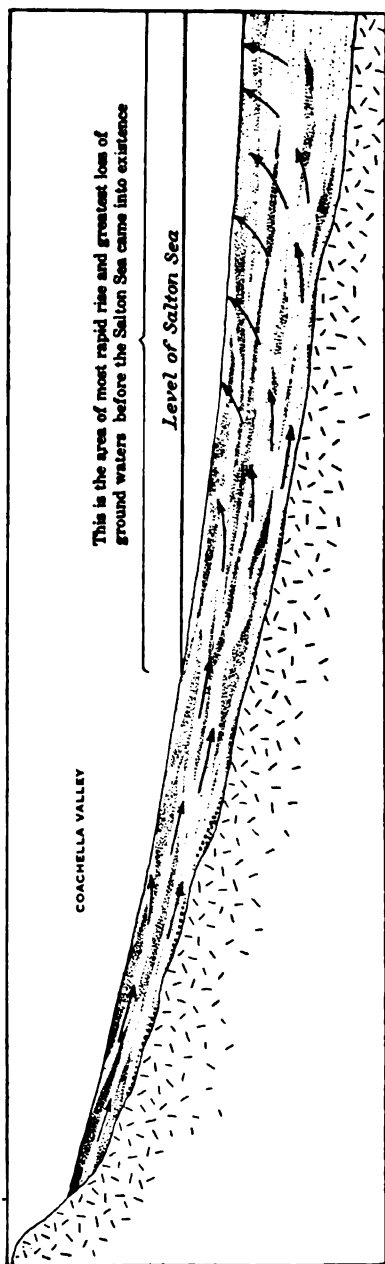


FIG. 5.—Diagrammatic section illustrating course of ground waters through Coachella Valley.

into the air annually from underground sources. In the spring of 1907 this basin was partially filled by a sheet of water covering an area of nearly 500 square miles and having a maximum depth of about 75 feet. A little consideration makes it evident that the existence of this water body must have a marked effect on the natural waste into the air of the subterranean supplies.

It is to be remembered, in the first place, that a certain analogy may be drawn between the underground flow of the Indio basin and the flow of a surface stream, although the analogy is not close at some points. Just as a surface stream has its source, its mid course, and its mouth or point of discharge, so has this body of ground waters a source, a mid course, and a point of discharge. Its source is in the alluvial fans, particularly their upper portions, where the surface waters sink and join the underflow. Its mid course is the Coachella Valley, through which the ground waters percolate slowly southeastward, in the direction of the general slope of the surface and presumably of the valley bottom, although its attitude must remain conjectural. The point of discharge of the ground waters is the Salton Sink, and indeed all the moist and practically all the alkaline areas about its borders.

Instead of discharging into a larger water body, as do surface streams generally, the ground waters discharge into the air by evaporation from the moist lands (fig. 5), a very minor part, of course, escaping through the springs that are found in the lower parts of the desert.

This escape is effected as a result of the hydraulic head of the ground waters and their constant tendency to rise as a consequence of this head, and, when they are near enough to the surface for it to act, as a consequence of capillarity also. The waters are removed by evaporation as quickly as they approach the surface. With this condition in mind, the effect of the water body in the Salton depression at once becomes apparent. It acts on the underground waters much as a dam across its mouth would act upon a river. A great part of the field from which the ground waters evaporated is covered by the lake and evaporation therefrom is prevented; and a part of the hydraulic head under whose influence the ground waters rose to the surface is balanced by the pressure of the lake waters, and this rise of ground waters is thereby interfered with (fig. 5). Very much less of the water of the Coachella Valley must be wasting now through evaporation than before the creation of the Salton Sea. No quantitative estimate can be made of this effect. It can only be said that it must be sufficiently powerful to be beneficial to the users of ground water in the Indio region.

This beneficial condition is necessarily temporary, as the Salton Sea is temporary. If the engineering work done and to be done about the intake of the Imperial Canal accomplishes its purpose of

preventing further inflow of the Colorado, the Salton Sea will probably have nearly disappeared by 1925; and as it gradually shrinks a larger and larger area will be exposed, through which ground waters will escape by capillarity and evaporation, until, with the disappearance of the sea, the conditions that prevailed before it came into existence will have been restored. From the point of view of the users of ground waters in the Coachella Valley, it is to be regretted that the sea can not be maintained at its present level.

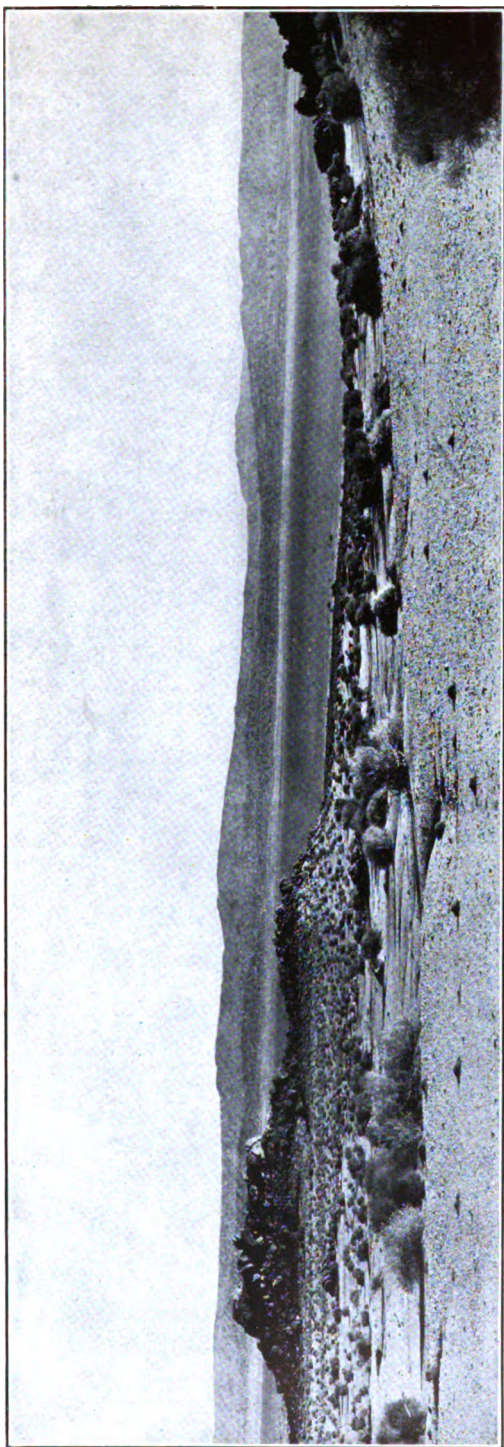
HISTORY OF DEVELOPMENT OF THE INDIO REGION.

In the Colorado Desert railroad building was encouraged by the Government in the same way as in other parts of the West—that is, every odd section of public lands for a number of miles on either side of its right of way was deeded to the railroad on condition that it should construct its line. Thus one-half of the lands in the Coachella Valley belong to the Southern Pacific. The railroad has disposed of a few sections near its track, but it still holds the greater part of the original grant, and agricultural development is therefore confined chiefly to the even sections.

The larger portion of these public lands were filed upon under the desert land act in 1885 and 1886. After the completion of the successful deep well at Walters in 1894, proving finally the presence of abundant artesian waters beneath this part of the desert, interest in the possibility of its reclamation was greatly stimulated, but the great cost of drilling wells by the ordinary method prevented further extensive development until 1900. In April of that year the first successful hydraulic well was put down at Indio. It reached a depth of 500 feet in seventeen hours, and the cost was comparatively nominal. From the date of its completion until the present development has been continuous, and now from 350 to 400 deep wells are scattered about over those parts of the desert which are accessible from the stations between Indio and Salton Sea. Of this number, from 250 to 300 are artesian. About 90 pumping plants have been installed, two or three wells frequently being coupled together and pumped from one station.

It is estimated that more than \$100,000 is invested in the artesian wells that have been bored in the valley, and that the pumping plants with the wells on which they are installed represent an additional expenditure of \$75,000. If the cost of reservoirs and of such pipe lines as have been put in are added, it will easily bring the total investment in works for the development and distribution of water to \$200,000.

By the use of the waters which have been developed in this way, 4,000 or 5,000 acres of land have been reclaimed and are successfully irrigated. The area in which flowing waters may be pro-



VIEW OF THE SALTON BASIN FROM THE WEST SIDE AFTER THE INFLOW OF THE COLORADO.

cured—it has been roughly outlined by the developments to date—covers approximately 140 square miles. This area extends from a point a short distance above Indio to a point below the present border of the Salton Sea. The greater part of it lies on the south side of the Southern Pacific Railway, but there is a strip from 1 to 2 miles wide on the north side of the line.

Much the stronger artesian flows are obtained at the lower elevations near the southern end of the belt. Wells at the upper or north-western extremity of the valley give inferior yields, so that it has been found necessary to pump from many of them in order to obtain sufficient water for successful irrigation. This condition is due in part to the originally inferior yield of these higher wells and in part to a decrease in their flow which has followed the increased development. All of the flowing wells lie below the sea-level contour. A few of the northernmost are very near sea level, but the most of them are from 20 to 150 feet below.

COST OF RECLAMATION AND DEVELOPMENT.

The value of lands within the desert depends on their situation relative to the railroad, their fertility, their freedom from alkalis, the improvements which have been made upon them, and the water supply. Those on which successful wells have been bored are, of course, more valuable than those whose water supply has not yet been proved. The unimproved lands have been sold at prices ranging from \$10 to \$100 an acre. Cultivated land with a proved water supply sells at from \$25 to \$200 an acre, or even higher in places where the improvements are extensive. Such land occasionally rents for as much as \$25 an acre. The majority of the active land-owners are residents, have small holdings of 10 to 80 acres, cultivate intensively, and do a great part of their own work. Absentee ownership and large holdings are comparatively rare. A great proportion of the work of clearing new land and preparing it for cultivation is performed by Indians from the reservations along the western side of the valley. They are paid \$2.50 an acre for clearing sagebrush and the smaller desert growths and 50 cents each for removing the mesquite trees. The wood obtained from these trees generally pays for the cost of their removal, as it is worth \$4.50 per cord at Thermal and Coachella. Some of the lands are covered with hummocks and require grading. The cost of this varies with the amount of work involved, and no accurate estimate can be given.

The drilling of wells by the hydraulic method now in vogue costs about a dollar a foot for both labor and casing for wells of the usual diameters—2 to 4½ inches. Those of larger size are somewhat more expensive. Artesian flows are procured at depths of 275 to 1,000 feet, the shallower waters being found in the southern and western

portions of the basin and the deeper ones in the northern and eastern sections. Wells alone, therefore, range in cost from \$200 to as much as \$3,000 each—the latter amount being given as the cost of the first successful deep well put down by the Southern Pacific Railroad by the old method, at Mecca.

The average flow is rarely great enough to enable ranchers to irrigate successfully direct from the well. It is customary, therefore, to build small earthen reservoirs (Pl. X, B) into which the water flows and from which it is conducted in comparatively large volume for purposes of irrigation. These reservoirs are of simple construction, the walls usually being thrown up by a team and scrapers. Some of them are lined with fine clay; others are unlined. Those that are unlined lose much water by seepage. The reservoirs are not covered, and the loss from them by evaporation during the summer must be considerable. Engineers of the Reclamation Service report that the annual evaporation at Yuma is from 80 to 85 inches or about 7 feet. It is probably not less from small water surfaces in the vicinity of Indio.

SOILS AND CROPS.

The soils of the Indio area have been carefully studied by J. Garnett Holmes, of the Bureau of Soils, U. S. Department of Agriculture. He divides them into five types, but of these the two most widely distributed and most important agriculturally are sandy loams that differ but slightly in coarseness of grain. Together they cover an area of 135 square miles. This area includes practically all of the valuable lands that are water bearing and yet lie above the extremely alkaline areas, which are extensive in the vicinity of the Salton Sea and along a line that follows approximately the lower part of the valley from the sink to the vicinity of Indio. Mr. Holmes says of the finer of these loams: "It is well adapted to any crop that is suited to the climate of the area. A better soil for general purposes would be difficult to find, since it is easily cultivated, very productive, and retains moisture well." It is worthy of note that these soils contain a very large percentage of calcium carbonate, ranging from a little less than 2 per cent to nearly 37 per cent in the various samples collected. It is not at all unusual to find soils containing 5, 6, and 7 per cent of this mineral. This high percentage is no doubt due to the very great number of small fossil shells that are scattered over the surface of this portion of the desert and through the soils which underlie it.

The agricultural development of the area is still in its infancy. The ranchers are experimenting on various crops and with various

^a Holmes, J. Garnett, and party, Soil survey of the Indio area, California; Field operations of the Bureau of Soils, U. S. Dept. Agr., 1903, pp. 1249-1262.

degrees of success. Those most extensively raised at present are melons, barley, and alfalfa. Small tracts, however, have been planted, chiefly for experimental purposes, in grapes, sweet potatoes, oranges, and sugar beets; and at the agricultural experiment station near Mecca rather extensive experiments are being conducted in date culture, a number of the finer, rarer, and more delicate varieties having been introduced from northern Africa and Arabia. Some of the date palms are in bearing, and those in charge of the experiment are sanguine as to its success.

The most highly specialized product of the region is the cantaloupe. The first experiment in its cultivation was made in the summer of 1900. A crate of melons raised during that season was shipped to Chicago, where, because of their high flavor, they found a ready market. Upon the basis of this first venture about 60 acres were planted during the following season, producing 13 carloads and netting to the growers \$10,000. The cultivation of this fruit has been successfully continued since, with a constantly increasing acreage. In 1904 the Melon Association of Coachella distributed \$67,000 to its members, and in addition the independent operators shipped 11 cars from Indiö. The success of the crop is due to the excellent quality of the fruit produced and to the fact that the climatic conditions of the desert permit its early marketing.

Alfalfa and barley are raised with unqualified success, but are less extensively cultivated than melons as a ready money crop. The grapes it is proposed to produce are the fancy table varieties, which the growers expect to place on the market early, as they do the cantaloupes. The vines that have been planted are thrifty, and the experiment promises to be successful. The sweet potatoes that have been produced thus far are excellent in quality; and although they mature early and may be marketed early if there is a demand for them, the growers have found that they are preserved in excellent condition in the dry soil of this climate for months, so that it is not necessary to dig them until market conditions are at their best. Some Indian and Kaffir corn is raised. Sugar beets have been tried as an experiment and have proved successful, but are not extensively cultivated because it is believed that larger returns may be obtained from other crops. Sugar beets have some alkali-resisting qualities and may therefore be raised in lands not suited to the cultivation of more sensitive crops. The date palm is even more capable of resisting alkali. This is especially true after it has become established and deeply rooted. Hence it may prove to be adapted to many soils in the valley where other crops can not be grown.

MAPS AND TABLES.

A map (Pl. XII) has been prepared on which the location of most of the producing wells that had been bored by April, 1907, is shown. the character of each well being indicated by an appropriate symbol. Ordinary domestic wells are represented by a single red dot, artesian wells by a red circle, and pumping plants by a red dot within a circle. Each well is numbered, and the essential facts concerning it—name of owner, location by land lines, diameter, depth, yield, temperature of waters, and cost—are given in the tables that follow. The map shows also approximately the outline of the artesian area, as determined by development, and the areas irrigated.

The data on which this map is based were collected in the field by A. J. Fisk, jr., and W. N. White, who have also rendered great assistance in the office in the preparation of the matter for publication.

Wells in *Indio special quadrangle* (Map, Pl. XII).

[Symbols used in tables: H=hydraulic; B=bored; Dr.=drilled; ? is used after all uncertain data.]

No.	Owner.	Location.		Year completed.	Class.	Well.		Depth.	Distance to water.	Temperature of water.	Method of lift.	Quantity of water.	Cost.
		Township.	Range.			Section.	Diameter.						
1	W. H. Harris.	6	8	23	H.	23	4 1/2 inches.	Feet.	Feet.	° F.	Artesian.	Miner's in.	\$600
2	do.	6	8	23	H.	23	do.	499		74	do.	a 12	600
3	H. J. Churchman.	6	8	23	H.	23	do.	509		74	do.	a 23	600
4	A. L. Gordon & Bro.	6	8	23	H.	23	do.	497		74	do.	a 20	600
5	do.	6	8	23	H.	23	do. (2).	512		76	Gas artesian.	a b 15 } a c 40 }	1,000
6	do.	6	8	23	H.	23	do.	512		76	Artesian.	a 15	500
7	J. W. Newman.	6	8	23	H.	23	do.	526		74	do.	a 15	500
8	G. J. Armstrong.	6	8	23	H.	23	4 1/2 inches.	538		74	Gas artesian.	a 6	1,100
9	S. B. Twomey.	6	8	25	H.	25	4 1/2 inches.	457		74	Artesian.	a 15	514
10	J. T. King.	6	8	26	H.	26	do.	514		74	do.	a 8	
11	C. B. Bisbee.	6	8	26	H.	26	3 inches.	601		74	do.	a 15	500
12	Mr. Holman.	6	8	23	H.	23	4 1/2 inches.	519		74	do.	a 15	500
13	W. H. Mather.	6	8	23	H.	23	do.	506		74	do.	a 25	450
14	Geo. Stephenet.	6	8	22	H.	22	4 inches.	488		74	do.	a 25	512
15	E. D. Morrill.	6	8	14	H.	14	8 inches.	86		6	Wind.	a 20	400
16	J. K. Ross.	5	7	14	H.	14	do.	238	6	76	Not raised.	a 30	500
17	do.	5	7	14	B.	14	do.	464	8		Artesian.	a 20	
18	U. S. Department of Agriculture.	7	9	16	H.	16	4 inches.	482			do.	a 15	
19	B. G. Johnson.	7	9	16	H.	16	4 inches.	839			do.	15	
20	Southern Pacific R. R. Co.	5	7	24	Dr.	24	do.	690			Steam, artesian.	a 30	
21	do.	5	7	24	Dr.	24	do.	695			Artesian.	a 25	
22	do.	5	7	22	Dr.	22	12 inches.	510			do.	a 1	
23	C. B. Smith.	7	9	22	H.	22	4 inches.	440			do.	a 25	
24	R. H. Myers.	7	9	22	H.	22	4 inches.	503			do.	a 14	
25	do.	7	9	22	H.	22	3 inches.	530			do.	a 10	
26	M. H. Flint.	7	9	26	H.	26	4 1/2 inches.	530		76	do.	a 10	500
27	H. J. Rogers.	7	9	26	H.	26	4 1/2 inches.	525			do.		202
28	W. V. Covington.	7	9	18	H.	18	2 inches.	525			do.		
29	do.	7	9	8	H.	8		525			do.		

a Estimated, or owner's statement used in column "Quantity of water."

b Flows.

c Pumps.
d Cost of well and pumping equipment used in column "Cost of well."

Wells in Indio special quadrangle (Map, Pl. XII)—Continued.

No.	Owner.	Location.			Year completed.	Well.		Depth.	Distance to water.	Temperature of water.	Method of lift.	Quantity of water.	Cont.
		Township.	Range.	Section.		Class.	Diameter.						
31	Walters school district.	S. 7	E. 9	8	1903	H.	2 inches	Feet. 500	Feet.	77	Artesian.	Miner's in. 8	
32	Mecca Land Co.	7	9	8	1901?	H.	3 inches	547		77	do.	11	
33	do.	7	9	8	1903	H.	3 inches	547		77	do.	13	5330
34	J. R. Robertson.	5	7	12	1904	B.	4 inches	531			Not raised.		200
35	do.	5	7	12	1904	B.	7 inches	186	12				200
36	do.	5	7	23	1896	B.	do.	165	17		Hand.		
37	Mrs. V. I. Norsden.	5	7	23	1901	H.	2 inches	465		73	Artesian.	2	
38	do.	5	7	23	1904	B.	4 inches	500			Gas, artesian.	38	b 1,400
39	H. Smith.	5	7	23	1899	B.	8 inches	218	11		Gas.		b 185
40	A. H. Moore.	5	7	23	1903	B.	do.	100	20		Wind.		b 900
41	N. O. Nelson.	5	7	23	1905	H.	7 inches	165	24		Gas.	18	
42	do.	5	7	23	1903	B.	3 inches	218	12		Compressed air.		
43	do.	5	7	23	1903	B.	8 inches	197	14		do.		
44	do.	5	7	23	1903	B.	do.	150	18		do.		
45	do.	5	7	23	1902	H.	do.	370	18		do.		
46	do.	5	7	23	1903	B.	3 inches	248	18		do.		
47	C. A. Hayott.	5	7	23	1903	B.	8 inches	150	18		do.		
48	P. B. Weir.	5	7	13	1903	B.	do.	155	18		do.		
49	do.	5	7	13		H.	2 inches	600+			Artesian.		
50	Ross estate.	5	7	14		B.	8 inches	480		78	do.		
51	Will Everett.	5	7	14		B.	2 inches			74	do.	4	
52	do.	5	7	14	1903	B.	7 inches	160	12		Wind.		
53	do.	5	7	14	1902	B.	do.	210	9		Gas.	5	
54	D. W. Durbrow.	5	7	23	1900	B.	do.	150	9		do.	4	
55	do.	5	7	23	1904	B.	6 inches	632		74	Gas, artesian.	40	
56	do.	5	7	23	1901	H.	do.	536			Artesian.	6	
57	Fred N. Johnson.	5	7	23		B.	4 in. (2)	600	0		Compressed air.		b 300
58	do.	5	7	23	1901	B.	6 inches (2)	150	16		do.		b 450
59	do.	5	7	22	1903	B.	7 inches	106	27		Wind.		b 500
60	do.	5	7	22	1904	B.	do.	170	27		do.		
61	Mr. Lewis.	5	7	10	1904	B.	do.	198	22		do.		
62	W. B. Peck Co.	5	7	22	1904	B.	7 inches (2)	100	17		Not raised.		
63	do.	5	7	22	1904	B.	8 inches	125	22		Compressed air.		
64	do.	5	7	22	1904	B.	do.	178	22		do.		
65	do.	5	7	22	1903	H.	do.	210	22		do.		
	do.	5	7	22	1907	H.	4 inches	634	7		do.		
	do.	5	7	22		H.	7 inches	78	22		Wind.		

Wells in Indio special quadrangle (Map, Pl. XII)—Continued.

No.	Owner.	Location.		Year completed.	Well.		Depth.	Distance to water.	Temperature of water.	Method of lift.	Quantity of water.	Cost.
		Township.	Range.		Class.	Diameter.						
115	Silas Trickey	S. 7	E. 9	20	1901?	II.	Feet.	Feet.	° F.	Artesian.	Miner's in.	
116	do	7	9	20	1901	II.	500+		76	do.	26	
117	E. A. Francis	7	9	8	1903	II.	500+		76	do.	31	\$400
118	do	7	9	8	1902	II.	500		77	do.	3	350
119	L. A. Teagle	7	8	12	1902	II.	464		74	do.	a 35	
120	do	7	8	12	1903	II.	434			do.	a 60	
121	H. J. Sternberg	7	8	2	1901	II.				do.		
122	do	7	8	2	1903	II.	436		74	do.		
123	do	7	8	2	1903	II.	495		74	do.		
124	do	7	8	2	1905	II.	499		74	do.		
125	C. D. Miller	7	8	2	1905	II.	477		74	do.	17	
126	D. F. Baxter	7	8	2	1902	II.	550		74	do.	26	
127	F. A. Leep	7	8	2	1901	II.	543		74	do.		
128	do	6	8	35	1903	II.	513		74	do.	13	565
129	R. B. Thayer	6	8	35	1902	II.	497		74	do.	23	500
130	do	6	8	35	1902	II.	465		74	do.	26	
131	do	6	8	35	1905	II.	504		74	do.	a 56	
132	do	6	8	35	1904	II.	514			do.	26	
133	E. N. Stanley	6	8	35	1904	II.	515		75	do.	33	
134	H. W. Cottle	6	8	35	1901	II.	560			do.	a 20	525
135	do	6	8	35	1905	II.	524			do.		
136	do	6	8	22	1903	II.	490			do.		
137	Toro Indian Reserve	7	8	28	1902	II.			79	do.	a 35	
138	do	7	8	28	1902	II.			79	do.	a 25	
139	do	7	8	26	1902	II.				do.	a 20	
140	Mr. Selig	7	8	34	1902?	II.	780		90	do.		
141	Southern Pacific R. R. Co.	6	8	5	1898	B.	412	4		Not raised		
142	Rector Bros	0	8	5	1904	II.	549		73	Gas, artesian.	b 15	
143	do	6	8	5	1902	II.	538			do.	a 69	
144	Town of Coachella	6	8	5	1899?	II.	545		73	Artesian.	a 4	
145	R. D. Smith	6	8	6	1899	II.	557		73	Hand, artesian.	2	
146	do	6	8	6	1902	II.	540			Gas, artesian.	b 7	42,550
147	do	6	8	6	1902	II.	542			do.	c 45	

LIST OF WELLS.

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No.	Name.	Year.	Depth.	Direction.	Remarks.	Notes.
148	do.	1902	31 in.	do.	do.	b 4
149	Ed. Geth.	1901	4 in.	do.	do.	7
150	do.	1901	4 in.	do.	do.	a 50
151	Geo. C. Huntington	1903	4 in.	do.	do.	a 2,000
152	A. Goleb.	1904	4 in.	do.	do.	a 18
153	do.	1902	8 in.	do.	do.	b 8
154	do.	1905	8 in.	do.	do.	a 40
155	F. R. Strong.	1902	2 in.	do.	do.	b 10
156	do.	1904	4 in.	do.	do.	a 140
157	Coschella Land and Water Co.	1902	8 in.	do.	do.	a 1,900
158	C. C. Robertson.	1901	2 in.	do.	do.	3
159	do.	1904	4 in.	do.	do.	a 40
160	Mr. Teagle.	1901	4 in.	do.	do.	a 2,000
161	M. J. Murray.	1901	4 in.	do.	do.	a 2,200
162	F. E. Holloway.	1904	4 in.	do.	do.	a 1,760
163	Rector Bros.	1901	4 in.	do.	do.	a 28
164	Coschella Bank.	1901	4 in.	do.	do.	a 2,300
165	Coschella Land and Water Co.	1901	4 in.	do.	do.	()
166	do.	1901	4 in.	do.	do.	()
167	do.	1901	4 in.	do.	do.	()
168	Rudlick & Trench.	1901	4 in.	do.	do.	()
169	Rector Bros.	1901	4 in.	do.	do.	()
170	H. Woods.	1901	4 in.	do.	do.	()
171	A. W. Haight.	1901	4 in.	do.	do.	()
172	Coschella Valley Refrigerating Co.	1901	4 in.	do.	do.	()
173	C. E. Mawby.	1901	4 in.	do.	do.	()
174	do.	1901	4 in.	do.	do.	()
175	C. Banta.	1901	4 in.	do.	do.	()
176	I. H. Fay.	1901	4 in.	do.	do.	()
177	C. O. Carlson.	1901	4 in.	do.	do.	()
178	do.	1901	4 in.	do.	do.	()

Pumps.
Small.

Wells in Indio special quadrangle (Map, Pl. XIV)---Continued.

No.	Owner.	Location.		Year completed.	Well.		Depth.	Distance to water.	Temperature of water.	Method of lift.	Quantity of water.	Cost.
		Township.	Range.		Class.	Diameter.	Feet.					
179	C. O. Carlson.....	S. 6	E. 8	8	H.	4 inches.	537			Artesian.	Mineral.	12
180	Hummel Bros.....	6	8	8	H.	(2 wells).	507			do.	a15	
181	G. M. Beach.....	6	8	8	H.	4 inches.	400			do.	22	
182	W. J. Hobbs.....	6	8	8	H.	4 inches.	485			do.	20	
183	do.....	6	8	8	H.	4 inches.	500			do.	21	\$500
184	Seth Hardison.....	6	8	7	H.	4 inches.	500			do.	a8	
185	do.....	6	8	7	H.	4 inches.	500			do.		
186	do.....	6	8	7	H.	4 inches.	500			do.		
187	Frank R. Strong.....	6	8	7	H.	4 inches.	508			do.	16	
187	A. J. Hoskin & Son.....	6	8	7	H.	4 inches.	520	8		Artesian, gas.	a40	\$1,712
188	N. C. Hanson.....	6	8	8	H.	4 inches.	522			Artesian.	a12	1,500
189	Mrs. N. C. Hanson.....	6	8	8	H.	2 inches.	540			do.		
190	J. P. Baker.....	6	8	8	H.	4 inches.	522			do.		525
191	Mr. White.....	6	8	8	H.	do.	550			do.	12	550
192	Coachella Land and Water Co.....	6	8	9	H.	do.	540			do.	a27	540
193	Dillman & Baldwin.....	6	8	7	H.	8 inches.	545			do.		
194	do.....	6	8	7	H.	7 inches.				Artesian and gas.		
195	Hugh Montgomery.....	6	8	7	H.	4 inches.	535			Gas.	5	535
196	S. C. Grindley.....	6	8	7	H.	3 inches.	540			Artesian.	a3	600
197	W. J. McMillan.....	6	8	7	H.	(3 wells).	500			do.	25	
197	do.....	6	7	12	H.	7 inches.	200	18		Gas.		
198	C. R. Cawthon.....	6	7	12	H.	3 inches.	200		72	do.		
199	do.....	6	7	12	H.	3 inches.	500		72	Artesian, gas.		
200	do.....	6	7	12	H.	8 inches.	110			do.	4	
201	Mr. Bauer.....	6	7	12	H.	3 inches.	500			do.	4	
202	J. Holliday.....	6	7	12	H.	4 inches.	500			do.		
203	Mr. Bauer.....	6	7	12	H.	4 inches.	177	20		Artesian, gas.	a25	
204	E. Holley.....	6	7	12	H.	4 inches.	500		72	Gas.	9	
205	do.....	6	7	12	H.	4 inches.	500		72	Artesian, gas.	a2	
206	do.....	6	7	12	H.	4 inches.	500			Artesian, gas.		
207	do.....	6	7	12	H.	4 inches.	500			Gas.	a40	\$1,426

204	Mrs. Kearny	6	7	16	1905	B.	do	215	43	Not raised	
205	E. Heller	6	7	16	1903	B.	7 inches	124	46	Gas	do
206	Tatti & Hall	6	7	16	1904	B.	8 inches	123	48	Gas	do
207	Masland & Green	6	7	6	1902	B.	7 inches (2)	100	45	do	do
208	A. P. Green	6	7	6	1903	H.	7 inches	190	45	Not raised	(d)
210	J. R. Thurmond	6	7	34	1903	H.	4 inches			Artisan	(d)
211	Mr. Bauer	6	7	26	1903	H.	3 inches	3007		do	(d)
212	Mrs. O'Flanagan	6	7	26	1903	H.	4 inches			do	(d)
213	Mr. Cohagen	6	7	26	1903	H.	do			do	1
215	J. R. Thurmond	6	7	26	1901	H.	do	329		do	13
216	J. B. Alvord	6	7	35	1903	H.	3 inches	320		do	10
217	do	6	7	35	1903	H.	10 inches			do	8
218	do	6	7	35	1903	H.	4 inches			do	7
219	J. S. Glenn	6	7	25	1903	H.	8 inches			do	(d)
220	do	6	7	25	1903	H.	4 inches	365		do	a9
221	O. C. Eberhardt	6	7	25	1903	H.	do	337		do	3
222	do	6	7	36	1901	H.	4 inches	340		do	3
223	do	6	7	36	1900	H.	2 1/2 inches	340		do	4
224	A. T. Mann	6	7	36	1901	H.	3 inches	340		do	7
225	J. Amsley	6	7	36	1901	H.	3 inches	340		do	11
226	G. L. Bugbee	6	7	1	1905	H.	4 inches	327		do	14
227	Dozier Lewis	6	7	36	1901	H.	3 inches	340		do	327
228	G. L. Bugbee	7	7	1	1905	H.	4 inches	370		do	6
229	G. L. Bugbee	7	7	1	1902	H.	4 inches (2)	340		do	26
230	J. A. Barton	7	7	1	1902	H.	5 1/2 in. (2)	385		do	30
231	Toro Indian Reserv.	7	7	1	1904	H.	4 inches	372		do	15
232	do	7	7	1	1903	H.	4 inches	282		do	17
233	do	7	7	2	1903	H.	4 in. (2)			do	
234	do	7	7	2	1903	H.	do			do	
235	Seth Hardison	6	8	18	1901	H.	4 inches			do	
237	Fred O. Todd	6	8	32	1902	H.	4 in. (2)	397		do	a14
238	do	6	8	32	1902	H.	3 inches	400		do	15
239	W. A. Snyder	6	8	32	1903	H.	4 inches	540		do	21
240	F. H. Hunt	6	8	32	1903	H.	4 inches	484		do	32
241	W. R. Prouty	6	8	32	1903	H.	3 inches	328		do	a1
242	do	6	8	32	1903	H.	4 inches	468		do	a23
243	Mr. Vogt	6	8	32	1901	H.	4 inches	458		do	a6
244	Stanley & Payne	7	8	4	1901	H.	do	474		do	17
245	Glenn Bros.	7	8	4	1901	H.	4 inches			do	a7
246	do	7	8	4	1901	H.	3 inches			do	
247	Mrs. T. F. Thompson	7	8	4	1904	H.	6 inches	440		do	a8
248	Thermal School District	6	8	22	1903	H.	4 inches	498		do	a8
249	A. P. Green	6	8	22	1900	H.	4 inches	375		do	14
250	Thermal Land Co.	6	8	22	1902	H.	5 inches	520		do	a25
251	do	6	8	22	1902	H.	do	520		do	a10

c Flows.

d Small.

a Estimated, or owner's statement used in column "Quantity of water."

b Cost of well and pumping equipment used in column "Cost of well."

Wells in Indio special quadrangle (Map, Pl. XII)—Continued.

No.	Owner.	Location.			Year completed.	Well.		Depth.	Distance to water.	Temperature of water.	Method of lift.	Quantity of water.	Cost.
		Township.	Range.	Section.		Class.	Diameter.						
252	Mr. Martin.	S. 9	E. 8	22	1901	H.	4½ inches.	Feet.	Feet.	° F.	Artesian.	Mineral.	
253	J. L. F. McLain.	6	8	26	1901	H.	4 inches.	520	74	74	do.	21	
254	do.	6	8	26	1904	H.	4 inches.	572	74	74	do.	16	
255	Martin & Moore.	6	8	26	1902	H.	3½ inches.	510	74	74	do.	19	\$570
256	do.	6	8	26	1900	H.	4 inches.	500	74	74	do.	11	
257	do.	6	8	26	1900	H.	do.	511	74	74	do.	9	
258	Megaw Bros.	6	8	26	1900	H.	4½ inches.	517	74	74	do.	16	
259	J. A. Potter.	6	8	35	1904	H.	4 inches.	509	74	74	do.	26	
260	Mr. Hutchings.	6	8	35	1904	H.	4 inches.	500	74	74	do.	19	
261	G. L. Keith.	6	8	35	1904	H.	4 inches.	500	74	74	do.	38	
262	Toro Indian Reserve.	2	8	22	1905	H.	4 by 4 feet.	577	74	74	do.	20	
263	do.	2	8	32		Dug.		18	16		Hand.		
264	Rector Bros.	6	8	4	1901	H.	4½ inches.	500			Artesian.		
265	Mr. West.	6	8	4		H.	do.	542		75	do.	12	
266	do.	6	8	4		H.	5½ inches.	500		75	do.	14	
267	Raddock & Trench.	6	8	4		H.	4 inches.	500		75	do.	8	
268	Rector Bros.	6	8	4	1902	H.	do.	500		75	do.		
269	do.	6	8	4		H.	do.	500		74	do.	16	
270	Thermal Land Co.	6	8	5	1904	H.	4½ inches.	574		74	do.	12	
271	do.	6	8	10	1903	H.	do.	526		75	do.	10	
272	do.	6	8	10		H.	do.	532		75	do.	10	
273	B. F. Boone.	6	8	10		H.	do.	517	0	75	do.	10	
274	do.	6	8	34	1902	H.	4 inches.	200	30	91	Gas.	35	\$ 1,500
275	do.	6	8	34	1901	B.	8 inches.	220	25	91	do.		
276	Mr. Ynost.	7	8	34	1901	B.	4 inches.	250		92	Artesian.	35	
277	Peera, Evans & Gage.	8	8	34	1901	H.	3 inches.	300		94	do.	35	
278	do.	8	8	24	1902	B.	10 inches.	315		90	do.	66	
279	do.	8	8	24	1902	B.	do.	315		88	do.	8	
280	F. S. Everett.	6	7	14	1899	B.	4 inches.		16		Wind.		\$ 350
281	do.	6	7	14	1903	B.	7 inches.	170	16		Gas.		
282	Southern Pacific R. R. Co.	8	9	2		B.	7 inches (2)	175	16		Artesian.	25	\$ 1,150
283	do.	8	9	2		H.	2 inches.	502			do.		
284	do.	8	9	2		H.	do.	708			do.		
285	do.	8	9	2		H.	do.	555			do.		
286	do.	8	9	2		H.	do.	589			do.		
287	Peera, Evans & Gage.	8	9	17	1902	Dr.	(2 wells).	460	5		Not raised.		
		8	8	24		B.	10 inches.	601					

288	Mr. Yost.	14	1905	11.	8 inches.	582	Artesian.	12	3,000
289	J. P. Klier.	8	1906	11.	4½ inches.	432	Gas, artesian.	16	432
290	C. B. Harris.	12	1906	11.	do.	464	Artesian.	70	310
291	do.	12	1904?	11.	4 inches.	413	do.	22	375
292	C. L. Edmunds.	2	1906	11.	4½ inches.	417	do.	24	375
293	do.	2	1906	11.	do.	407	do.	33	25
294	D. K. Baxter.	2	1903?	11.	do.	517	do.	13	15
295	J. P. Read.	35	1906	11.	do.	530	do.	15	540
296	J. S. Leach.	26	1905	11.	do.	503	do.	3	500
297	A. W. McGill.	26	1906	11.	do.	513?	do.	10	515
298	Martin & Moore.	26	1906	11.	do.	580	do.	5	3
299	J. H. Bell.	26	1906	11.	do.	489	do.	3	1,700
300	C. B. Bisbee.	23	1905	11.	do.	485	Gas, artesian.	4	1,700
301	Butler Bros.	8	1907	11.	do.	375	Artesian.	18	15
302	Mrs. Brook.	8	1907	11.	do.	497	do.	40	3
303	Adams & Butman.	8	1907	11.	do.	436	do.	34	34
304	do.	8	1907	11.	do.	322	do.	20	15
305	Oakley Wood.	8	1907	11.	do.	483	do.	15	9
306	Payne Bros.	8	1905	11.	do.	486	do.	9	30
307	Holland Bros.	8	1907	11.	do.	240	Gas.	30	1,025
308	do.	8	1907	11.	do.	160	do.	9	30
309	J. H. Thurston.	5	1905	B.	6 inches (2)	1,052	Artesian.	30	1,025
310	D. C. Huntington.	5	1905	B.	6 inches.	100	Gas.	65	435
311	C. W. Hyde.	5	1906	B.	8 inches.	221	do.	2	Not used.
312	S. Starett.	5	1906	B.	do.	100	Wind.	15	Not used.
313	W. A. Caldwell.	5	1906	B.	do.	119	do.	16	Not used.
314	C. B. Estle.	5	1906	B.	do.	150	do.	16	Not used.
315	Geo. Gillons.	5	1907	H.	4½ inches.	136	Gas.	20	435
316	Mr. Baeyeritz.	5	1906	H.	5½ inches.	1,000+	Artesian.	2	Not used.
317	J. A. Semple.	5	1907	H.	3 inches.	80	Not used.	15	Not used.
318	G. W. Durbrow.	5	1907	B.*	6 inches(?)	119	Wind.	16	Not used.
319	C. F. Cooper.	5	1907	B.*	7½ inches.	119	Wind.	16	Not used.
320	Fred N. Johnson.	5	1907	B.	7½ inches.	119	Wind.	16	Not used.

^a Estimated, or owner's statement used in column "Quantity of water."

^b Cost of well and pumping equipment used in column "Cost of well."

^c Flows.
^d Pumps.

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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, DIRECTOR

WATER-SUPPLY PAPER 226

THE POLLUTION OF STREAMS BY
SULPHITE PULP WASTE

A STUDY OF POSSIBLE REMEDIES

BY

EARLE BERNARD PHELPS

Investigation made at the Sanitary Research Laboratory and Sewage Experiment Station
of the Massachusetts Institute of Technology



WASHINGTON
GOVERNMENT PRINTING OFFICE
1909

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THE POLLUTION OF STREAMS BY SULPHITE PULP WASTE—A STUDY OF POSSIBLE REMEDIES.*

By EARLE BERNARD PHELPS.

INTRODUCTION.

The pollution of streams by the waste liquors resulting from the manufacture of paper pulp by the sulphite process constitutes one of the most serious stream-pollution problems with which science has to deal at the present time. The seriousness of the problem is the direct result of two factors—the tremendous volume of such waste liquors and their high content of organic matter of extremely undesirable character. An approximate estimate of the amount of sulphite waste liquor discharged into the streams of the United States in one year is given in the subjoined statement, compiled from data in Forest Circular No. 120, Forest Service, United States Department of Agriculture.

Amount of sulphite waste liquor discharged into streams of the United States during 1906.

	Million gallons.
Maine	560
Massachusetts	45
Michigan	175
New Hampshire	380
New York	1,000
Ohio	41
Oregon	52
Pennsylvania	217
Virginia	84
West Virginia	89
Wisconsin	540
All other States	44
	3,227

According to the above estimate, the total amount of this liquor discharged into streams throughout the country in one year is more than three billion gallons, and when it is considered that of this enormous amount 10 per cent by weight, or more than 2.5 billion pounds, is solid matter, mostly organic, it will be readily conceded that the problem of its disposal is one of no small magnitude.

* This investigation was made in cooperation with the sanitary research laboratory and sewage experiment station of the Massachusetts Institute of Technology.

STREAM POLLUTION BY SULPHITE PULP WASTE LIQUOR.**GENERAL DISCUSSION.**

Though the pollution of streams by sulphite pulp waste is an obvious and serious matter in the region where sulphite mills exist, the literature contains but few references which throw any light on the actual damage caused. In Germany the regulations of the sanitary authorities are strict. Ahrens ^a states that pulp manufacturers, in spite of constant endeavor, may come into conflict with the authorities because they are not able to meet the requirements in regard to the discharge of waste waters into rivers, and he adds that many factories in Germany have actually been obliged to shut down for that reason. Sanitary officers in the United States are more lenient. This is due partly to the fact that the streams in this country are larger and the greater number of the sulphite mills are located in less densely populated regions.

POLLUTION OF LAKE CHAMPLAIN.

In some places stream pollution from this cause has been so serious as to warrant investigation. Leighton,^b in his investigation of the pollution of Lake Champlain, made a study of sulphite pulp waste as it affects Ausable River, which he found to be a black, foul, grossly polluted stream in which the existence of fish or other forms of life is impossible. He concluded, however, that the great dilution of the river waters by those of the lake renders the pollution insignificant so far as the lake waters are concerned.

POLLUTION OF JAMES RIVER.

Levy^c made a careful study of the effect of sulphite waste pollution on James River. The sources of pollution are at Covington, Va., about 250 miles by water above Richmond, whose public supply is derived from this stream. Levy found Jackson River, into which this liquor is discharged and which unites with the Cowpasture below Iron Gate to form the James, to be perfectly clear and colorless. The waste entering the stream first turns the water dark brown and later a purplish black. Foam is created at the outfall and wherever the stream is interrupted by falls or by rapids. This appearance can be noted for the entire distance from Covington to Richmond. Dilution is practically the only means of improvement. On the sanitary side of the question Levy considers two problems—(1) whether

^a *Zeitschr. angew. Chemie*, 1895, p. 41.

^b Leighton, M. O., Preliminary report on the pollution of Lake Champlain: Water-Supply Paper U. S. Geol. Survey No. 121, 1905.

^c Levy, E. C., Report to the water committee on the investigation of the effect of trades wastes on the water of James River at Richmond. Richmond, 1905.

the substances introduced are themselves actually injurious to health, and (2) what influences they may have on the multiplication of bacteria. The liquor itself as it enters the river is absolutely sterile, not only on account of the actual germicidal substances which it contains, but also on account of the fact that it has been subjected for about twelve hours to steam under a pressure of 80 pounds to the square inch. Its germicidal properties are shown in the following table:

Germicidal action of sulphite waste liquor on bacteria in highly polluted water from Shockoe Creek.

[By E. C. Levy.]

Per cent, by volume, of liquor in mixture.	Number of bacteria per cubic centimeter.			Per cent of reduction (-) or increase (+).	
	At start.	After 6 hours.	After 24 hours.	In 6 hours.	In 24 hours.
0 (control).....	450,000	900,000	2,500,000	+100	+ 455
1.....	445,000	.....	^a 7,500,000	.....	+1,585
5.....	427,500	60,000	170,000	- 86	- 60.2
10.....	405,000	35,000	0	- 91.4	- 100
25.....	337,500	10	0	-100	- 100

^a Plate liquefied.

The number of bacteria in the water at the commencement of the experiment is calculated from the number of bacteria present in the creek water itself (450,000). Where the reduction is more than 99.95 per cent it is given as 100 per cent. Even very small amounts of the waste liquor have an antiseptic action, but are not actually germicidal; they restrain the growth of bacteria without killing them. Such action may be harmful rather than otherwise, for in a stream receiving sewage certain kinds of bacteria eventually render the sewage harmless. It would seem that as the character of this waste is so stable it does not furnish food for bacterial growth.

Complaint is made that the water of the James at Richmond is unfit for boiler use; both on account of its corrosive action and on account of the "priming" due to vegetable matter present. Aside from the matter of actual harm, however, Levy states that the water is rendered objectionable in appearance by this waste. The dark-brown, almost black water, with its accumulation of dirty scum, is not relished by the consumer, even if he knows that it is probably safe to drink it. In a bath tub this color is very pronounced, and even in so small a quantity as a tumblerful it is decidedly noticeable. James River is practically clear for certain periods of each year, and at such periods, under normal conditions, no further treatment than mere storage would be required for furnishing satisfactory water. But during these periods, on account of the low stage of the

river, the trouble from Covington is most marked. Plain sedimentation has absolutely no effect on the color; but coagulation will remove a large part of it, and Levy found not less than 3 grains of alum per gallon necessary for this purpose. He estimates that with a daily consumption of 14,000,000 gallons it would cost \$75 a day for alum, which would not be required if it were not for the sulphite pollution, and states that even then the water would not be perfectly satisfactory.

Farther up the river complaints have been made that fish have been killed by the sulphite waste. The opinion is expressed that if fish are killed it is perhaps because the free oxygen, which is necessary for their life, is used up, rather than because of the presence of substances actually poisonous in themselves.

POLLUTION OF POTOMAC RIVER.

Some experiments to determine the effect of sulphite waste pollution on fish life in Potomac River are reported by Marsh.^a He found a decidedly injurious effect on fish of different kinds in dilutions varying in strength from 1 part of waste liquor in 50 parts of water to 1 part in 200 parts of water.

POLLUTION OF BLACK RIVER.

Whipple^b has referred to the effect of sulphite pollution on the water supply of Watertown. He states that the sulphite liquors contribute to the odor and color of the water, and necessitate the use of greater amounts of alum than would otherwise be necessary.

MANUFACTURE OF SULPHITE PULP.

In order that the character and amount of the waste liquors resulting from the manufacture of wood pulp by the sulphite process may be comprehended it will be necessary to describe, in some detail, the various operations that are conducted in a sulphite mill to convert spruce logs into paper pulp. The processes in use at the Mechanicsville mill of the West Virginia Pulp and Paper Company will be described, as they are typical of a modern sulphite mill of average capacity. Though there are naturally many variations in minor details, the essential steps are similar at all mills, so that a detailed description of the processes of one mill, with an occasional statement of important alternative methods, will serve the purpose of this discussion.

^a Marsh, M. C., in Parker, H. N., and others, The Potomac River basin: Water-Supply Paper U. S. Geol. Survey No. 192, 1907.

^b Whipple, G. C., Proc. Watertown Soc. Eng., Watertown, N. Y., 1906.

THE WOOD.

Spruce and hemlock are the woods used almost exclusively for the manufacture of pulp by the sulphite process. The logs are either barked by hand in the woods before seasoning or by machinery at the mill. Machine barking necessitates cutting the log into 2-foot lengths; in hand work 4-foot lengths are used without further cutting. Machine barking also causes some waste of material through cutting too deeply into the log. Some measurements of logs barked by machinery show that the original circular section of the log had been changed to that of a circle minus 6 small segments, the area of the segments being found to be 18 per cent of that of the original circle. All logs are carefully inspected at the mill, and those in which there is evidence of decayed portions or unremoved bark are rejected. Subsequently a man removes the bark and decayed places from these imperfect logs with an ax. The logs are thrown into a large tank of hot water to loosen the ice, dirt, and sand which have adhered to them. They then pass through scrubbers, in which a powerful spray of water removes all the sand and cinders. They are then ready for the chipper. This machine consists essentially of three knife blades in a rapidly revolving vertical steel disk. One end of the log is pressed against these blades at an angle, and in a few seconds the log is reduced to chips. The resulting fragments are then run over screens to separate them into three portions. Everything that passes through a $\frac{1}{4}$ -inch mesh is discarded. This chip dust is at present practically a waste product, though it is used to some extent for packing ice and for bedding horses. A half-day test at the Mechanicsville mill showed that 1,375 pounds of chip dust, or about 2.7 per cent of waste, resulted from chipping 17 cords of wood. The chips which do not pass through a 1-inch mesh are next separated and passed through a machine known as a shredder. This machine, working on a novel principle, crushes the large chips into shreds and separates the good wood from the knots to a large extent. The shredded mixture is then "floated" over a long water tank, in which the knots, by virtue of their greater specific gravity, sink to the bottom. The separation here is almost complete, and the removal of the knots at this time is of great benefit, as they interfere seriously with subsequent operations. The middle portion of the chipped mixture, which is retained on a $\frac{1}{4}$ -inch screen and passes through a 1-inch screen, goes directly by belt conveyors to the storage bins over the digesters, as does also the floated portion of the shredded chips after a second screening. The chips are now ready for the digester.

THE ACID LIQUOR.

The solution of chemical reagents used in the digester to dissolve out of the wood all intercellular and other noncellulose matter consists essentially of calcium and magnesium bisulphites with an excess of free sulphurous acid. It is made by passing sulphur dioxide

through a suspension of milk of lime made from dolomitic lime, through towers of limestone over which water is trickling. The former process is in most general use in this country. A suspension of slaked lime (milk of lime) is made, having a strength of about 1.2° B.—that is, about 1.3 percent $\text{Ca}(\text{OH})_2$. Gaseous sulphur dioxide is prepared either by roasting pyrite or by burning sulphur directly in specially designed burners. The gases are passed through lead pipes submerged in large tanks, through which cold water is running, as it is essential to keep the absorption apparatus as cool as possible. The cooled gas next goes into a tank of milk of lime, which is nearly saturated by allowing the gas to enter at the bottom and to bubble up through the liquid. The unabsorbed gas is conducted from the top of this tank to the bottom of a second tank filled with fresh milk of lime, where the absorption is completed. The residual gases then pass to the pumps, which maintain a partial vacuum in the tanks and insure a constant flow of gas. During absorption the contents of the tank are constantly stirred. When the acid liquor in the first tank is of the requisite strength, as shown by analysis, it is pumped into the acid storage tanks, the second tank is emptied into the first, and fresh lime is added to the second. The process of absorption is then repeated. The composition of the acid liquor varies in different mills and even in the same mill from time to time as the quality of wood varies. A specimen analysis of the liquor, expressed in the mill terms, showed free sulphur dioxide, 2.5 per cent; combined sulphur dioxide, 1.1 per cent; a total of 3.6 per cent. "Free sulphur dioxide" is the total acidity of the solution expressed as SO_2 . It is therefore the free dissolved gas plus one-half the sulphur dioxide present as bisulphite. The "combined sulphur dioxide" represents the rest of the bisulphite radicle. The actual composition of the liquor is therefore as follows, the total base being regarded as calcium:

Analysis of sulphite liquor.

	Per cent.
Calcium (Ca).....	0.7
Sulphur (S).....	1.8
or, in combination—	
Calcium bisulphite ($\text{CaH}_2(\text{SO}_3)_2$).....	3.5
Dissolved sulphur dioxide gas (SO_2).....	1.4

For one charge of a digester of average dimensions, 12.8 by 34 feet, producing about 7 tons of dry pulp at each "cook," 16,000 gallons of acid liquor are used.

THE DIGESTER.

The digester consists of an upright steel cylindrical shell with a conical bottom and a nearly hemispherical top, lined with lead, within which is another lining of resistant glazed brick, pointed with a special mortar. Older forms of digesters have concrete linings. The inside dimensions of a digester of average size are, diameter 12.8 feet, total height 34 feet, and its capacity is about 2,700 cubic feet.

THE "COOK."

About 12 cords of wood chips are first placed in the digester, and then about 16,000 gallons of the acid liquor are run in, filling the digester within 6 feet of the top. The shell is then closed tightly and steam is admitted. The contents are brought rapidly to boiling temperature and then the pressure is raised gradually to about 65 pounds, two hours being consumed in this heating. During the next two hours the pressure is increased more slowly to about 80 pounds. At this point the digester is full of liquor, the water condensed from incoming steam having completely filled the space which was left at the time of filling. In order, therefore, to add more steam it is necessary to "relieve." This process consists in allowing the liquor slowly to escape from the top of the digester as steam enters at the bottom. This relief liquor is strongly acid, and as a rule is returned to the acid-liquor tanks to be used again. There is some objection to such recovery of the relief, because it is rather dark colored and is apt slightly to color the next "cook." The temperature is carefully noted and frequent analyses of the liquor within the digester are made during the "cook," especially during the last two hours. Small samples for analysis are drawn from a tap in the side of the digester near the top. They are examined for total sulphur dioxide and the color and odor are noted. If in the opinion of the attendant the reaction is proceeding too fast, the incoming steam and the relief are both shut off and the "cook" is "held." It is intended to complete the "cook" in about six hours. Nearly at that time the sulphur dioxide content begins suddenly to fall, the color becomes darker, and a peculiar characteristic odor develops. The reactions at that time are proceeding very rapidly and the charge must be blown immediately or a dark-colored stock will result. The skill of the operator is here well shown in bringing about this rather sharp end point at almost the exact time desired, six hours. A large blow-off valve is then opened at the bottom of the digester and its entire contents are blown under full pressure into the blow pit, which is a large covered wooden tank, 22 feet in diameter and 20 feet deep, provided with a large air shaft for the escape of the steam and gases. Opposite the end of the pipe leading from the digester there is a bronze baffle plate, against which the contents of the digester are thrown with great force. The pit is provided with a false bottom and the liquor is rapidly drained off. It is essential at this point to remove all the acid liquor as rapidly as possible. After the blowing the liquor darkens rapidly from a light-garnet shade to nearly black, and its retention in the pulp results in a dark-colored product. About 15,000 gallons of wash water are added as soon as possible and drained off. A second washing is then given with the same amount of water, when the

drains are closed, more water is added, and the stock is ready to be pumped to storage tanks. A small amount of the acid liquor is taken out during the "cook" as relief, but the principal part of it is discharged at the end of the "cook," constituting the sulphite pulp waste liquor.

SCREENING AND WASHING THE STOCK.

The two processes of screening and washing the stock are carried on simultaneously, and can best be described together. The stock is pumped from the blow pit into storage tanks, from which it is pumped as fast as needed into an elevated tank, flowing thence to the screens and the washing machinery. It first passes through a long revolving cylindrical screen, slightly inclined from the horizontal and provided on the inside with a continuous worm-shaped vane. This screen is very finely meshed, and its function is to remove a large part of the water from the stock. Next the stock passes into a similar cylinder with rectangular meshes about one-fourth of an inch wide and 1 inch long. The wood fiber is washed through these meshes by the aid of a stream of water playing from above. All knots and undigested chips are retained in this screen, collected at its open end, and measured, the amount and character of the undigested portions being regarded as a valuable criterion of the care with which the preceding processes have been conducted. On the average, there will be about 4 cubic feet of this material per "cook," or a little over half a foot per ton of dry pulp. The stock passes from these screens to the settling tanks or "riffles," long troughs about 6 feet wide and 2 feet deep, provided with baffles on the bottom for the retention of sediment. The object of the tanks is to remove by sedimentation any sand or grit which may have gained access to the stock from the machinery or otherwise. The stock is now ready for the final screening, by which it is separated into marketable stock and tailings. The tailings from the first screening process are generally run through a second screen and a little good fiber is saved in that way. The final tailings are passed over a wet machine and felted into low-grade pulp, which is sold for use in the manufacture of leather board. The screened pulp also is passed over a wet machine, which is essentially a revolving screen that separates the bulk of the water from the pulp, leaving the latter in a rather thick sheet. If the pulp is to be sold or used as unbleached pulp, it is taken from the wet machine at this point, passed between large wooden rollers, and finally removed in the form of thick sheets of wet pulp. If it is to be bleached, it is removed mechanically from the rolls of the wet machine, mixed with a large volume of water, and conducted to the bleach tanks.

BLEACHING THE STOCK.

The unbleached pulp as it comes from the wet machine has a very slight brownish color, although it appears pure white to the inexperienced eye. If such pulp is made into paper, however, it is likely to darken rapidly with age and drying, so that pulp for high-grade papers must be bleached with chloride of lime. Commercial chloride of lime, or bleaching powder, consists mainly of calcium hypochlorite, and it is made by passing free chlorine gas over quicklime. The trade name, chloride of lime, is therefore a misnomer. A typical analysis, by Wagner,^a of bleaching powder of good quality is given herewith:

Analysis of chloride of lime.

Calcium hypochlorite ($2\text{CaOCl}_2 + \text{H}_2\text{O}$)	82.65
Calcium carbonate (CaCO_3)	.95
Calcium chloride (CaCl_2)	.44
Calcium hydrate ($\text{Ca}(\text{OH})_2$)	6.80
Water (H_2O), free	9.82
	100.66

Inasmuch as the chlorine alone of the hypochlorite is available for bleaching purposes, a sample of bleaching powder having the above analysis would contain 43 per cent of "available" chlorine and would be called a 43 per cent bleach. The product on the market seldom contains so much chlorine as that, good grades in this country running from 35 to 40 per cent available chlorine.

The bleaching powder, or "bleach," as it is called in the mill, is received in large iron casks, each holding about 600 pounds. They are emptied into a mixing tank with approximately 3 gallons of water to a pound of bleach. Generally, an ordinary tank provided with a rotary agitator is used for this mixing, but at the Mechanicsville mill an improved mixer is in service, which appears to be very efficient. The tank is conical in shape, about 15 feet high and 10 feet in diameter at the top, tapering to a point at the bottom. A centrifugal pump with a 3-inch discharge is near the tank at its bottom level. This pump withdraws the liquid mixture from the bottom of the tank and discharges it horizontally into the upper part in a direction tangential to the periphery. Circulating the liquor through the tank in this manner produces an immense vortex, so that, although the liquor whirls about the sides of the tank to the level of the inlet, one can look down into this vortex almost to the bottom of the tank. This process accomplishes a thorough mixing of bleach and water in a comparatively short time. The mixture then flows into a large brick

^a Wagner, R. von, *Manual of chemical technology*; trans. from 13th German ed. by Sir William Crookes, New York, reprint of 1904, p. 360.

settling tank and is allowed to settle until a clear liquor can be decanted. This liquor is tested for strength with a Baumé hydrometer and is mixed with the proper amount of a weak bleach extract to give it the required strength of about 3° B. This weaker solution is made by a second extraction of the sludge or "grout" remaining after the first decantation. The grout is usually strengthened by the addition of a small amount of fresh bleach, agitated with a fresh supply of water, and again submitted to sedimentation. The liquor obtained constitutes the weak bleach mentioned above, while the sludge remaining, the "second grout," is agitated a third time with fresh water and again settled. The third lot of supernatant liquor constitutes the water used in the first extraction of a new lot of bleach; the "third grout" is a waste product. Reference to the analysis already given will show that it consists essentially of calcium hydrate, with more or less carbonate of calcium and other impurities derived from the original lime from which the bleaching powder was prepared.

The bleach solution of about 3° B. is mixed with pulp in the proportion of about 30 gallons of solution to 100 pounds of pulp.^a The mixture is passed successively through a series of tanks, eight in number, in which it is brought to and maintained at a temperature of about 100° F. and is mechanically stirred. Tests of this mixture are constantly being made as it passes from each tank to the next, and additional bleach solution is added as required, the processes being so regulated that, after the complete treatment, requiring about six hours' time, the pulp will be satisfactorily bleached and the bleach will be exhausted as completely as possible. It is next necessary to wash out of the pulp mixture the residual bleach and the calcium chloride resulting from the process. This is accomplished by first passing the stock under a series of washers. A washer is essentially a frame, in the form of an eight-sided prism, covered with fine-meshed copper gauze, and mounted on a horizontal axis, so that it is about half submerged in the pulp. It rotates slowly in the direction of the moving stream of stock, and as the water passes through the gauze it is collected in buckets suitably arranged within, elevated to a position above the center line of the box, and discharged through a side outlet. By this means a considerable volume of water is separated from the stock. Fresh water is admitted after each treatment and the washing is repeated several times, after which the washed stock is passed over a wet machine as previously described. It is then either pressed into sheets of wet pulp or, if it is to be used at once in the mill, is removed from the rolls by a stream of fresh water and run directly to the paper mill.

^a All references to pulp in these processes are to the actual weight of air-dry pulp in the mixture, though the pulp is always mixed with a considerable amount of water throughout the process of manufacture.

SUMMARY.

The various processes described in the foregoing pages have been arranged for convenient reference in diagrammatic form in Plate I. The raw materials that enter into the process are shown along the top line of the diagram in capitals. They are wood, lime, sulphur (or pyrite), bleaching powder, and water. Arranged vertically at the left is a list of the waste and by-products of the process, namely, bark, sawdust, knots, sulphite waste liquor, sand and grit, and sludge or grout from the bleach-solution tanks. Much of the water used in the later processes is returned and used for washing the freshly cooked pulp, so that practically the only liquid waste is the waste acid liquor and the first wash waters, these together making up the sulphite waste liquor. At the bottom of the diagram the finished products of the process are shown, namely, low-grade unbleached pulp and bleached sulphite pulp. Disposal of the grout involves no serious difficulties. It is usually discharged into low-lying fields or into artificially constructed basins, where it is converted into compact masses of carbonate of lime. The small amount of chip dust is readily used in ice houses or as a bedding material for horses. The bark if removed at the mill is either burned or given away for fuel, though it is generally more economical to have the barking done before shipment. In the study of stream pollution, therefore, consideration need be given only to the combined waters resulting from the digestion of the chips and the subsequent washings of the pulp—that is, the liquor here called the sulphite pulp waste liquor.

SULPHITE PULP WASTE LIQUOR.**PREVIOUS INVESTIGATIONS.**

This waste, arising as it does from an industry involving elaborate chemical methods and necessarily employing skilled paper-mill chemists, has probably received more careful and systematic study than any other waste product of the present day. A prize of 10,000 marks was offered in Germany in 1894 for the best method of preventing the pollution of streams by sulphite liquor, but it still remains unawarded. Scores of processes for utilizing or purifying the waste have been patented in Germany, England, and the United States, but none of them has been sufficiently successful to relieve, in any noticeable degree, the burdensome situation. Technical literature contains reports of exhaustive researches on the constitution of the organic substances found in this liquor, but there is no satisfactory agreement on this point. No more striking commentary on the difficulty of the problem can be made than the bare statement that, in spite of all these researches, the substance is still classed as a waste

product. According to Cross and Bevan,^a who summarize a paper by H. Seidel,^b no satisfactory application of this by-product has yet been evolved. Evaporation and combustion involve losses of sulphur.^c A more complete regeneration of the sulphur has been the subject of a series of patents.^d The process of V. B. Drewson^e consists in heating with lime under pressure, yielding calcium monosulphite. The sulphite is redissolved as bisulphite by treatment with sulphurous acid. This process is relatively costly, and yields necessarily an impure lye. It has been proposed to employ the product as a foodstuff both in its original form and in the form of benzoate;^f but its unsuitability is obvious from its composition. A method of destructive distillation has been patented. Seidel,^g however, found on investigating the process that the yield of useful products is much too low for its economical development. Fusion with alkaline hydrates for the production of oxalic acid^h is also excluded by the low yield of the product. The application of the liquor to tanning purposesⁱ appears promising from the fact that 28 per cent of the dry residue is removed by digestion with hide powder, but this application has been investigated without practical success. Various probable uses are suggested by the viscosity of the evaporated extract, but as a substitute for glue it has proved of little value. It is also used to some extent as a binding material in the manufacture of briquets and as a substitute for gelatine in the petroleum industry. Cross and Bevan^j and Mitscherlich^k precipitate a compound of the lignone complex and gelatine by adding a solution of the latter substance to the sulphite waste liquors. The compound is redissolved in weak alkaline solutions and employed in this form for engine-sizing papers. Ekman has patented a process^l for "salting out" the lignone sulphonates, the product being resolvable in water and the solution having some of the properties of a solution of dextrin. Owing to its active chemical properties this product, "dextron," has a limited capability of being substituted for dextrin. The suggestion to employ the evaporated extract as a reducing agent in indigo dyeing and printing has also proved unfruitful. Seidel's application of the soda salt of the lignone sulphonic acid as a reducing agent in chrome-

^a Researches on cellulose. 1895-1900 p. 150.

^b Zeitschr. angew. Chemie. 1900.

^c German patents Nos. 74030 and 83438; also Seidel and Hanak, Mitt. Techn. Gew. Mus., 1898.

^d German patents Nos. 40308, 68892, 71942, 78306, and 81338.

^e German patent No. 67889.

^f German patent No. 97935.

^g German patent No. 45951.

^h German patent No. 52491.

ⁱ German patent No. 72161.

^j British patent No. 1548, 1883.

^k German patents Nos. 93944 and 93945.

^l German patent No. 81643.

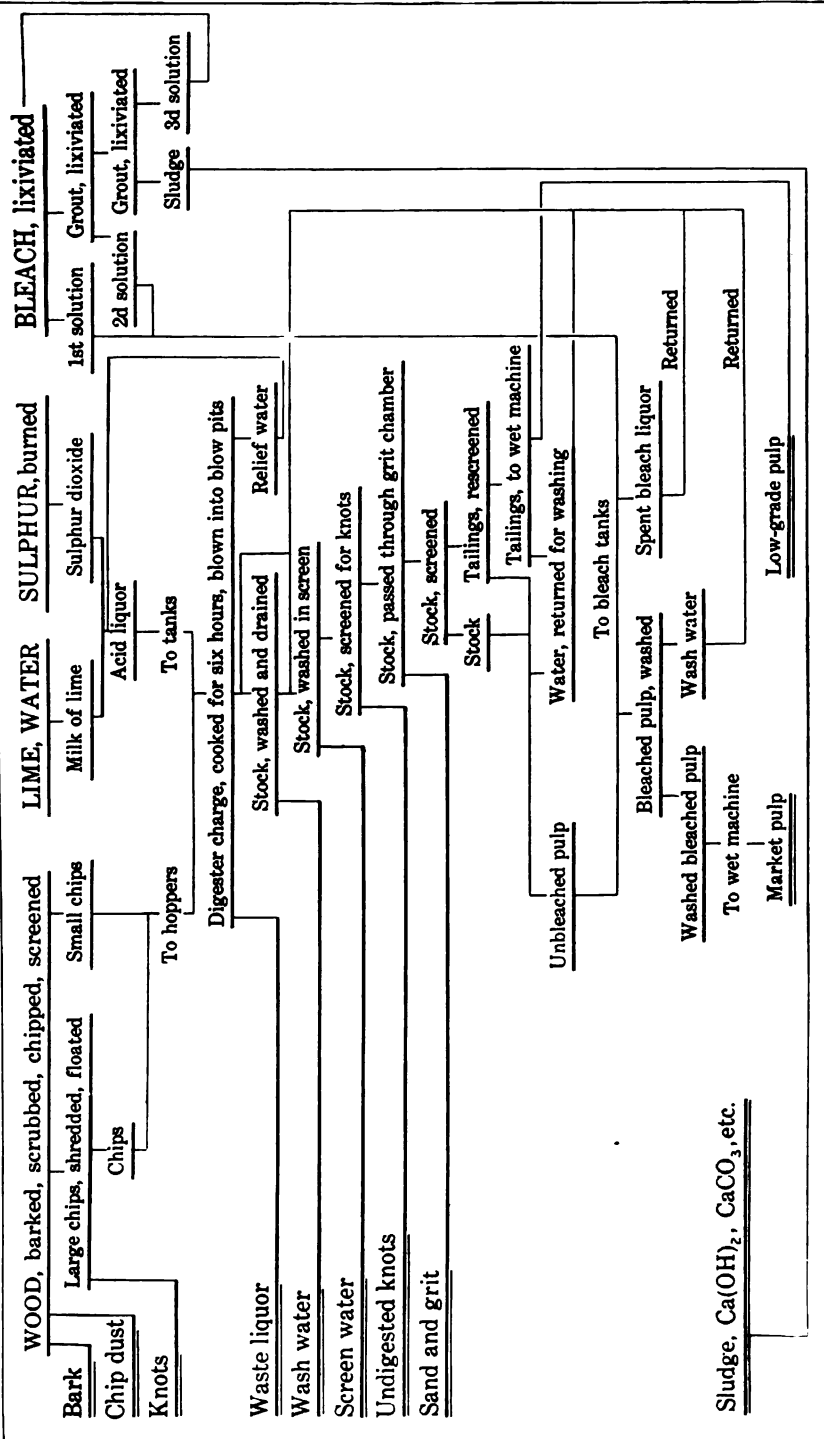


DIAGRAM ILLUSTRATING THE STEPS IN THE MANUFACTURE OF WOOD PULP BY THE SULPHITE PROCESS.

mordanting wool and woollen goods^a is more successful in practice, and its industrial development shows satisfactory progress. The product is known as "lignorosin." In another place, however, Cross and Bevan^b comment on this process by calling attention to the fact that such use for a by-product, produced in such enormous quantities, is of relatively small importance.

It is remarkable that the main by-product of the bisulphite process is still for the most part an absolute waste, notwithstanding the many investigations of technologists and attempts to convert it to industrial use. As it represents a percentage of the wood pulped equal to that of the cellulose obtained, it is a waste of potentially valuable material that must be termed colossal. Moreover, as a waste to be discharged into watercourses, it becomes a source of burden and expense to the manufacturer, and with the increasing restrictions on the pollution of rivers it constitutes in many localities a problem to be solved only by the cessation of the industry. The alternative in such cases is dealing with it destructively—that is, by evaporating and burning it. In this treatment the high calorific value of the organic matter appears on the credit side; but, as calcium and magnesium bisulphites are used, the residue from calcination is practically without value. If, however, a soda base is substituted, the alkali is recoverable in such form as to be directly available for the alkaline-sulphide or Dahl process. As a more complicated alternative the soda can be recovered by the old black-ash or Leblanc process, and the sulphur by the now well-established Chance process, in which lime must be added to the concentrated liquors before calcination. The engineering features of the system in respect to evaporating and calcining are the same. Economic working requires (a) evaporation by multiple effect and (b) calcining on the continuous rotary principle. For the latter process the draft of air is concurrent, by a special device, with the movement of the charge in the furnace, a feature by which a progressively increasing temperature within the furnace is procured. This interesting development has been elaborated by Drewson and Dorenfeldt, to whose publications readers who wish to inform themselves in detail in regard to these developments are referred. The present necessity of a destructive treatment of the sulphite waste liquor being assumed, their scheme has many advantages; sodium bisulphite liquors are more economically prepared and the pulp obtained is superior in paper-making quality and in economy of bleaching to that resulting from the calcium or magnesium bisulphite processes. The soda may be recovered in a form in which it is immediately available as a powerful hydrolyzing alkali in the

^a German patent No. 99082.

^b A text-book of paper making, 2d ed., 1900, p. 143.

manufacture of soda pulp, so that these two systems become complementary to one another. The employment of soda as the base also affords a new motive for developing the electrolytic processes of decomposing salt.

Cross and Bevan's comments present an excellent summary of conditions at the close of 1900. Significant of more recent developments in the methods of utilizing or disposing of this waste is the fact that in their second volume of "Researches,"^a a treatise purporting to review all work of importance on cellulose industries during the years 1900-1905, these authors make no mention whatever of the sulphite waste problem.

AMOUNT OF WASTE PER TON OF PULP.

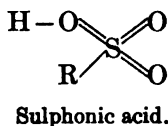
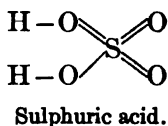
It is now practicable to inquire more carefully into the amount of the waste and its general characteristics. The important facts to be considered in any discussion of stream pollution are the amount and the character of the polluting material independent of the amount of water in which it may be carried. Chemical analyses of the waste liquor in connection with accurate determinations of its volume would furnish the requisite information, and such procedure is usually adopted. In the present case, however, it happens that the amount of polluting material bears a definite relation to the total product of the mill in pulp, independent of slight modifications of the process, whereas the amount of diluting water varies greatly in different mills and even from time to time in the same mill. For example, some mills use the old-fashioned rotary digesters, in which it is not necessary to use more than half the amount of water in the acid liquor that is used in upright digesters. The washing process is often conducted at places where water is plentiful, with a total disregard of economy in water, while in other mills strict economy of water is necessary; therefore the concentration of the waste liquors may be three or four times as great in one case as in another. In view of these facts and of the statement made above, that a definite amount of polluting material is produced for each ton of pulp turned out, it appears that the best procedure is to determine the definite relationship between the amounts of pulp and solid waste. Results obtained at one mill are applicable to any mill using a similar process, though the actual volumes of the wastes may be greatly different. After having determined this fundamental relation, it is of interest to compare the figures obtained with actual analyses of the waste liquor. Such comparison will give an approximate measure of the volume of diluting water.

^a Researches on cellulose, 1900-1905.

A cord of spruce wood ordinarily handled at the mill will weigh about 3,600 pounds, of which about 55 per cent, or 2,000 pounds, is actual wood substance, the remaining 45 per cent being water. The amounts of chip dust, knots, etc., which are really insignificant as compared with the total weights, may be neglected in this calculation. About 1,100 pounds of so-called "air-dry" pulp having 10 per cent water, or, roughly, 1,000 pounds of actually dry pulp, is made from 1 cord of wood. Therefore the production of 1 ton of pulp is accompanied by the production of an equal amount of waste organic material that is discharged in the waste liquor. According to the analysis on page 10, the sulphite liquor contains 0.7 per cent of calcium and 1.8 per cent of sulphur, equivalent, respectively, to 0.058 pound and 0.150 pound per United States gallon. On the basis of 16,000 gallons of acid liquor to a digester charge, which produces 7 tons of air-dry pulp, each ton of pulp is represented by 132 pounds of calcium and 343 pounds of sulphur. About 0.1 per cent of sulphur dioxide, or 9 pounds of sulphur per ton of pulp, is left unoxidized at the end of the "cook." Of the remaining 336 pounds of sulphur 10 per cent may be allowed for loss of free sulphur dioxide in the relief, leaving approximately 300 pounds of sulphur which has been oxidized in the process. The first product of this oxidation is probably sulphuric acid, according to the following equation, the oxygen being derived from the wood during the digestion:



This presents the simplest idea of the digestive action. Sulphurous acid is oxidized to sulphuric acid with a corresponding reduction of the wood substance. The fate of the sulphuric acid thus formed has not been satisfactorily determined. It is known that in the final product there is little free sulphuric acid. The first effect of its formation would be the precipitation of calcium sulphate, probably on the wood fibers. As magnesium sulphate is soluble, this is probably the reason why dolomitic lime gives such excellent results. If, however, all the calcium or magnesium originally used were converted to sulphate, there would be needed for that reaction only 100 pounds of sulphur, leaving still 200 pounds of sulphur unaccounted for. It will be shown when the chemical nature of the waste is considered that, according to prevailing views, the sulphuric acid from this amount of sulphur again reacts with a portion of the wood substance to form a so-called sulphonc acid. This may be regarded as sulphuric acid in which one of the OH groups has been replaced by an organic radical (R) thus:



This reaction is not complete and a small amount of sulphuric acid is generally left in the liquor. For the present it will not be necessary to discuss the relative amounts of these two acids. The waste material resulting from the digestion of sufficient wood to make 1 ton of pulp may be summarized as follows:

Materials in the waste liquor per ton of pulp.

	Pounds.
Wood material.....	2,000
Calcium sulphate.....	449
Sulphur dioxide (omitted from total).....	18
Sulphur in sulphuric acid and in organic combination.....	196
Total solid matter.....	2,645

CHEMICAL COMPOSITION OF THE WASTE LIQUOR.

As has been stated, the actual strength of the waste liquor is entirely a matter of dilution. The 16,000 gallons of acid liquor used in the "cook" producing 7 tons of air-dry pulp is usually diluted with one to two times its volume of water in the blow pit, and other waste waters later mingle with this liquor in the drains. For the purpose of study, however, it is advisable to procure samples of the undiluted waste liquors directly from the digester, because in any plan for the recovery of this liquor it will undoubtedly prove advantageous to separate the undiluted liquor. For the investigation here reported samples of the liquor were collected from the bottom of the digester just before blowing. The hot liquor was drawn into a barrel, allowed to cool, and then bottled in carboys for future use. The subjoined table gives analyses of this liquor and the figures of several analyses of similar liquors by other chemists.

Analyses of sulphite pulp waste liquor.

[Grams per liter.]

	1.	2.	3.	4.	5.	6.	7.	8.	9.
Total solids.....	95	82	88	85	93	92	109	52	54
Loss on ignition.....	82	68	75	69	81	90	90	45	46
Ash.....	13	14	13	16	12	19	19	17	8
Analysis of ash:									
Calcium (Ca).....	2.2						6.9	1.76	2.2
Magnesium (Mg).....	1.2						1.18	.97	1.2
Sulphur (S).....	2								
Total sulphur.....	10.5					9.2			
Free sulphur dioxide (SO ₂).....	1	2.6	2.2	2.9	2.6	3.8		.94	
Sulphite radicle (SO ₃).....		7.3	7.9	6.7	1.2	3.8	3.8	1.10	
Sulphate radicle (SO ₄).....		4.1	5.4	4.8	2.7	1.9	7.2	9.2	
Oxygen consumed.....	36	52	52	50	60				
Specific gravity.....								1.024	

^a Exclusive of the organic S.

No. 1, by the writer, is the average of two analyses of waste liquor collected directly from the digester at the Mechanicsville mill. Nos. 2 to 6, inclusive, are quoted by Hoffmann,^a Nos. 2, 3, 4, and 5 being

^a Hoffmann, C., *Practisches Handbuch der Papier Fabrikation*, Berlin, 1897.

by Wickelhaus,^a and No. 6 by Lehman. No. 7 is given by Schubert,^b and Nos. 8 and 9 are taken from the notebook of S. C. Lindberg, paper-mill chemist, who has kindly permitted their use.

These analyses give an excellent idea of the general character of the liquid. The proportions of the various constituents are in agreement with the figures which have been calculated from the amounts of raw materials used. The analyses also determine satisfactorily the nature of the inorganic matter in the waste and show the relatively large amount of organic matter present, about 80 per cent of the total solids.

CHEMICAL NATURE OF THE ORGANIC MATERIAL.

Thus far only the total amount of waste material in the liquor resulting from the digestion of 1 ton of dry pulp and its division into organic and inorganic constituents have been considered. The chemical nature and the essential characteristics of the organic matter deserve further consideration. Though our knowledge of the chemistry of wood is not extensive, the following facts seem to be definitely settled and may be accepted as embodying all that is positively known. The wood substance itself, freed from the relatively small amount of intercellular matter, such as gums and sap constituents, is a homogeneous material of fairly constant composition. To this substance chemists have given the name ligno-cellulose. Ligno-cellulose can be broken down by suitable chemical treatment into two or more substances. These are cellulose, which is the material of the wood pulp, and a complex substance or mixture variously called lignose, lignin, or lignone. It is this latter body or mixture of bodies which in the sulphite process is supposed to be sulphonated, giving rise to a substance known as lignon-sulphonic acid. The constitution of this substance is not known, nor is its chemical identity even assured. Beyond these meager facts all is hypothesis, despite the large amount of experimental work which has been done on the substance under discussion. Probably the best estimate of the character of lignone is given by Cross and Bevan,^c who made an exhaustive study of the subject.

They conclude that it is a single substance made up of (a) $2C_{18}H_{18}O_{10}$, a ketone transitional to quinone which chlorinates directly to marriogallol; (b) $6C_5H_4O_2$, furfural, in combination by condensation with (a) and (c); and (c) $5C_2H_4O$, acetic residue. The simplest empirical formula for their lignone is $(C_6H_6O_3)_n$, n being not less than some

^a *Papier Zeitung*, 1895, No. 38.

^b Schubert, Max, *Die Cellulose Fabrikation*, Berlin, 1892.

^c Cross, C. F., and Bevan, E. J., *Contributions to the chemistry of lignification*: *Jour. Chem. Soc.*, vol. 15, trans., 1889, p. 199.

multiple of 24. Tollens^a gives as the result of his analysis of the sulphonated form the empirical formula—



This formula must be slightly modified in view of Cross and Bevan's satisfactory determination of the presence of 5 acetic residues in the C_{76} molecule, instead of 6, as given by Tollens's formula. It has been stated that the chemical identity of the sulphonated form has never been satisfactorily shown. The experimental work on sulphite liquor, conducted by the author, seems to prove that the substance in question is probably not a true sulphonic acid.

PURIFICATION OF SULPHITE WASTE LIQUOR.

Investigations on the disposal of waste liquors may be carried out either with the object of recovering and utilizing the material contained therein or with the simpler aim of purifying the liquid so that it may safely be discharged into a stream. The former method of investigation has appealed most strongly to manufacturers and chemists, and a great many attempts have been made to discover some useful by-product in the waste sulphite liquors. Reference to these investigations will be made later. Owing to the failure in general of all such attempts and to the stringent laws against stream pollution, particularly in Germany, some attempts have also been made simply to purify the liquor by precipitating the organic matter, the experiments having no reference to the recovery of valuable by-products. One of the earliest of these investigations was made by H. Frank,^b who gives the following composition of the sulphite waste which he used:

Composition of sulphite waste.

	Grams per liter.
Total solids.....	82
Loss on ignition.....	59
Ash.....	23
Calcium (Ca).....	5.3
Magnesium (Mg).....	.25
Sulphate radicle (SO_4).....	14.4

In the process developed by Frank the liquor is treated first with lime to neutralize the free acid and then with chimney gases to carbonate the excess of lime and oxidize the calcium sulphite. A heavy precipitate of sulphate and carbonate is formed and it is claimed that much of the organic matter is dragged down, so that the supernatant liquid could be discharged into the stream. This process was later investigated more thoroughly by F. B. Ahrens, E. Klingstein, and P. Schubert,^c who state that many German wood-pulp

^a Quoted by Cross and Bevan, *Researches on cellulose*, p. 126.

^b *Wien. Jahresbericht*, 1887, p. 1177.

^c *Zeitschr. angew. Chemie*, 1895, p. 41.

mills have been compelled to close because it was found impossible to comply with the requirements of rivers-pollution officials. The examination of the waste sulphite liquor which they used showed that it gave a strongly acid reaction, had a specific gravity of 1.0465 at 15.8° C., and was optically inactive. The dry residue was 9.4 per cent, of which 1.11 per cent was ash and 8.29 per cent organic matter—not strictly accurate determinations. The liquors from the digesters were nearly neutralized by passing them over limestone. The hot lye was then mixed with a known quantity of fresh lime water once boiled, filtered, and the filtrate neutralized with carbonic-acid gas. The results obtained are shown in the following table:

Results of experiments in neutralizing hot sulphite waste liquors.

CaO added.	Analysis of supernatant liquor.		
	Dry substance.	Ash.	Organic matter.
<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
2	8.75	1.80	6.95
3	7.48	1.59	5.89
4	7.36	1.71	5.65
5	7.13	1.56	5.57
6	6.86	1.52	5.34
7	6.74	1.58	5.16
8	6.65	1.54	5.11
9	6.61	1.57	5.04
10	6.79	1.51	^a 5.28
11	6.54	1.55	4.99
12	6.52	1.49	^a 5.03
15	6.31	1.49	4.82
20	7.00	1.60	^a 5.40
30	4.99	1.01	3.98

^a Organic matter rendered soluble again by boiling.

When the liquors were treated cold, the following results were obtained:

Results of experiments in neutralizing cold sulphite waste liquors.

CaO added.	Analysis of supernatant liquor.		
	Dry substance.	Ash.	Organic matter.
<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
2	6.21	1.11	5.10
3	6.19	1.33	4.86
4	5.26	1.00	4.26
6	5.08	1.04	4.04
8	4.96	1.10	3.86
10	5.67	1.22	4.45
12	5.76	1.23	4.53
14	6.26	1.29	4.97

Sodium aluminate was also tried as a precipitant, but the results were less satisfactory. The precipitated and neutralized liquors were then treated electrically. A current of 5 amperes and only sufficient

potential was passed through the liquid between platinum electrodes, but no diminution in either mineral or organic matter was observed after two hours. A high-tension current (106 volts) was then tried, but the results were equally ineffective after a test of the same duration. It is evident, these authors conclude, that the objectionable organic matter, if removable at all, calls for some process hitherto undiscovered. Ahrens tried, unsuccessfully, to treat this waste bacterially after neutralization on the lines of his patent. It was found absolutely sterile to begin with, and the amount of bacterial filtration required for its decomposition was altogether impracticable. E. Bruch^a found that if the waste liquors are treated when acid, or neutral, with leather glue, a compound of tannic acid and glue is formed which coagulates on storing and becomes highly viscid. If then the clear, colorless top liquor is decomposed with aluminum sulphate, another gummy precipitate is formed. Both precipitates are soluble in alkalies and in weak ammonia, and may be removed, dried, and powdered. If the clear liquor is then neutralized with chalk or lime, a precipitation and clarification ensue, and the top liquor is free from smell and has lost about 25 to 30 per cent of the total organic constituents, and these the most easily decomposable.

UTILIZATION OF SULPHITE WASTE LIQUOR.

By far the most important work on this waste liquor has had for its object the utilization of the organic matter. Its complex chemical nature and relatively large amount and the fact that it is still a chemical mystery make the field particularly inviting for research. In some interesting laboratory experiments made by Buddens,^b and quoted by Griffin and Little,^c the waste liquor was neutralized by ammonia, the lime was precipitated by ammonium carbonate, and the carbonate of lime thus formed was separated by filtration. The dark-brown filtrate was evaporated and the dried residue distilled. The dried residue contained 7.2 per cent of ammonia as salts. Water and a yellow oil were obtained in the condenser, and finally a crystalline sublimate appeared on the walls of the tube. The escaping gases were caught in a gasometer. The oil had at first a mercaptan-like odor, but this disappeared on heating slightly. The odor was without doubt due to organic sulphur compounds, which were present in traces. The mixture of oil and water was, after this heating, distilled with steam, the distillate was shaken out with ether and then dried, and the ether was evaporated over calcium chloride. The brown oil that remained boiled at 130° C., and as it colored a pine chip moistened with hydrochloric acid a strong

^a Die Abwässerreinigung der Cellulose-Fabriken und die Papierleimung: Chem. Zeitung, 1892, p. 1782.

^b Buddens, W., Papier Zeitung, March, 1891.

^c Griffin and Little, Chemistry of paper making, New York, 1894.

carmines, it was believed to be pyrrol. Pyrocatechin was also found in the distillate, as was proved by color tests with iron salts and by the reduction of Fehling's solution. The gases from the first distillation were carbon monoxide, hydrogen, marsh gas, and hydrogen sulphide. Four hundred grams of the residue yielded 180 grams of coke, 30 liters of gas, and 200 grams of distillate. Mucic and saccharic acids could not have been present as such in the liquor, because they are formed by the oxidation of carbohydrates, and the action of the liquor is a reducing one. Yet pyrrol is formed by distilling the ammonium salts of these two acids. The only way of accounting for pyrrol is by considering that succinic acid is formed from the resins in the wood—a not improbable assumption. Ammonium succinate changes readily into ammonium succinamide, which gives pyrrol when it is heated with reducing agents. The presence of pyrocatechin is due to the presence of dioxybenzoic acid (1, 3, 4), which is in the liquor as dipyrrotechnic acid. The decomposition of this acid by distillation with ammonia produces tannic acid and pyrocatechin. Doctor Buddens states that there is no tannic acid in the liquor, which will give a blue-black color with ferric chloride, because the tannin in wood is reduced by digesting with sulphurous acid. The reduction is probably due to dipyrrocatechuic acid, but by treating the liquor with ammonia and distilling, tannic acid is eventually formed. Sulphites are oxidized to sulphates when the tannin is reduced. It is possible, therefore, that the difficulty of pulping wood rich in tannin by the sulphite process is due to the action of the tannin, which renders the sulphurous acid ineffective. Lindsey and Tollens,^a in their systematic search for the different sugars, used liquor from a Mitscherlich slow-process cook, with a specific gravity of 1.055, showing total solids 9.5 per cent, and calcium 0.41 per cent. The solution was pale yellow in color and strongly reduced Fehling's solution. They found no evidence of the presence of saccharose, dextrose, or dextrose-yielding sugars, traces only of levulose or levulose-yielding sugars, and but a small amount of galactose. On the other hand, mannose, determined as a hydrazine, was found to represent 6 to 7 per cent of the original total solids. Furfural was found in some quantity on heating with hydrochloric acid, and xylose was identified in the solution. Alcoholic fermentation of the liquor gave amounts of alcohol corresponding to only 1.2 per cent of the total carbohydrates. The remaining gummy mass behaved as a homogeneous complex, yielding several synthetic preparations, the analyses of which were consistent with the view of its homogeneity.

^a Liebig's Annalen, No. 267, 1892, p. 341. Abstracts Jour. Chem. Soc., 1892, p. 802.

A summary of various attempts to recover valuable products from the waste has already been given (pp. 15-18). Thus far no satisfactory recovery of valuable chemical substances has been made. The substance itself has been used as a substitute for glue and for sizing. Mitscherlich precipitated the tannin compounds with glue in the presence of alum and sulphuric acid, obtaining a rubbery mass, soluble in weak alkali, which could be used in engine sizing. He later improved the process^a by precipitating with lime to remove the sulphite present and then diffusing the liquor through membranes. The diffusible portion contained sugars and was fermented for alcohol. The nondiffusible part was treated as described above in order to remove the tannins. A later patent^b describes a process in which, after the removal of the calcium salts, the liquor is heated with hair or bone to give a semiwaterproof sizing. V. Drewnen and L. I. Dorenfeldt^c treat the liquor with soda ash recovered from the soda pulp process, precipitating the lime and a part of the organic matter. They draw off the clear liquor and burn the residue, using the heat of the combustion to evaporate more liquor. The liquor is said to contain more calorific energy than is necessary to evaporate it. The soda ash is recovered from the residue by the usual process, and about 60 per cent of the sulphur is recovered by liberating free sulphur dioxide with carbon dioxide gas. The fumes and the gases from the evaporation were found to be very corrosive. This trouble was finally overcome by combining the wastes of the sulphite and soda pulp mills and treating them like soda wastes. Frank's process, as described by Schubert,^d consists in precipitating the remaining calcium bisulphite as normal sulphite with excess of lime, after which the precipitate is redissolved in an excess of sulphur dioxide. Such treatment would recover only a small part of the total sulphur. Meyer's process, also described by Schubert,^e seeks to recover valuable products by destructive distillation of the organic material in the waste. The liquors are neutralized, concentrated to a thick sirup, mixed with charcoal to a paste, and distilled. The yield of valuable products is too small to make the process economical. H. Seidel has employed the soda salt of the lignone sulphonic acid as a reducing agent in chrome mordanting wool, where, under the name "lignorosin," it is used in place of tartaric and lactic acids.^f The material, especially when concentrated, is very sticky, and many attempts have been made to utilize it as a substitute for glue. In J. S. Robe-

^a United States patent No. 681241, 1901.

^b United States patent No. 687844, 1901.

^c United States patents Nos. 620755, 1899, and 726036, 1902.

^d Schubert, Max, *Die Cellulose Fabrikation*, Berlin, 1892.

^e *Op. cit.*

^f *Rev. gén. des mat. col.*, vol. 2, 1898, p. 370. *Jour. Soc. Chem. Ind.*, vol. 17, 1898, p. 1043. British patent No. 19005, 1897. German patent No. 99682, 1897.

son's process^a for the manufacture of an adhesive, which is being used at Ausable Forks, N. Y., by a large mill,^b the waste liquor is neutralized with lime and evaporated in vacuo. The product is a thick, molasses-like fluid, which finds application in foundries as an adhesive in core making. C. H. Voight^c makes a glue substitute by heating starch and a peroxide with the sulphite liquor. A. G. Brooks^d evaporates the liquid till it contains 20 per cent water, then adds carbohydrates or albuminoids and dries the mass, which is used for fuel, pitch, glue, resin, or size. Knoesel^e concentrates to 25° B. and treats with a slag meal high in phosphorus (Thomas slag). It is claimed that the phosphorus of the slag is rendered soluble in citrates and becomes available in fertilizing. Ahrens^f investigated the process and could not substantiate its claims. Processes have been proposed for the destructive distillation of the substance, and, as has already been stated, both pyrrol and pyrocatechin have been obtained in this manner. The yield of these products has not been sufficient to make the process successful. Patents have been granted for processes involving the use of the liquor in tannin.^g According to Seidel^h 28 per cent of the solids are removed by rawhide powder. No satisfactory method has yet been described for separating the tannin substance from the remainder. This seems to be one of the important lines for future investigation. Morteradⁱ subjects the hot liquors to a partial vacuum and removes from them a considerable volume of sulphur dioxide. Bergerhopf^j made a cheap grade of paper for newspapers by using the waste liquors to digest sawdust. Eckman^k "salts out" the liquors and makes a concentrated solution, which he calls "dextrone," a substitute for dextrin, or British gum.

EXPERIMENTAL INVESTIGATIONS WITH THE ORGANIC MATERIAL.

The knowledge of the chemical reactions which characterize lignone is very meager. Early in the present study it was deemed important to obtain additional light on the general behavior of this material. It was hoped that in this way knowledge of its chemical nature might be enlarged and particularly that some reactions of industrial value

^a United States patent No. 833634, 1906.

^b Paper Trade Journal, Jan. 5, 1905, p. 12.

^c United States patent No. 770202, 1904.

^d British patent No. 8088, 1901.

^e Jour. Soc. Chem. Ind., 1902, p. 489.

^f Chem. Zeitung, vol. 4, 1905, p. 40. Chem. Centralbl., vol. 1, 1905, p. 700. Jour. Soc. Chem. Ind., vol. 14, 1905, p. 343.

^g German patent No. 72161.

^h Zeitschr. angew. Chemie, 1900, p. 951.

ⁱ United States patent No. 833936, 1906.

^j German patent No. 160651, 1903. Jour. Soc. Chem. Ind., vol. 24, 1905, p. 1028.

^k German patent No. 81643.

might be discovered. For this study preparations of the dry material were made in various ways; the solubility of these preparations was investigated; attempts were made to identify a sulphonic acid in the material; and various other reactions were studied.

PREPARATION OF CRUDE "LIGNONE."

Three different preparations of the dry material were used. "Lignone A" was obtained in dry form at the mill. It was observed that certain steam pipes passing near the blow pit were heavily coated with a hard vulcanite-like substance, nearly an inch thick in places. About a pound of this material was chipped off and used in certain of these experiments. "Lignone B" was the supposed calcium compound obtained by evaporating the liquor to one-half volume and salting out with common salt. A granular amorphous substance, containing some salt and moisture, was obtained. "Lignone C" was supposed to be the sodium compound. When the liquor was neutralized with sodium carbonate and allowed to settle, a large amount of calcium carbonate was precipitated. The remaining liquor was evaporated and salted.

SOLUBILITY OF CRUDE "LIGNONE."

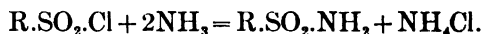
The solubility of each of these preparations was tested with several solvents in an endeavor to obtain a liquid from which the material could be crystallized. No solution took place in either hot or cold benzoin, amyl alcohol, allyl alcohol, petroleum ether, amylene, amyl acetate, aniline, toluene, xylene, nitrobenzene, carbon bisulphide, ethyl ether, or benzol. Benzoin seemed to soften the substance. The tests were repeated after acidifying to see if a free acid could be found which would dissolve, but the results were again negative. The two alcohols dissolved the samples if diluted with water. Ordinary ethyl alcohol also dissolved it, a result probably due to the water present. Absolute ethyl alcohol was not tried.

REACTIONS WITH PHOSPHORUS CHLORIDES.

An important general reaction of sulphonic acids is that with phosphorus pentachloride, giving sulphon-chlorides according to the reaction—



Sulphon-chlorides are for the most part insoluble oils which combine with ammonia to form crystallizable sulphonamides, as follows:

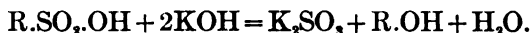


Appropriate mixtures of the crude "lignones" with varying amounts of the pentachloride, the oxychloride, and mixtures of the two were made. No indication of any reaction was obtained at room tempera-

ture or at temperatures up to 180°C. , at which point the oxychloride begins to distill. Altogether about twenty attempts were made to bring about this reaction. The products after heating were treated with ammonia, but no evidence of any amide was ever obtained. It must be concluded, therefore, that the "lignone" does not react with the chlorides of phosphorus in the way which characterizes sulphonic acids in general.

FUSION WITH ALKALI.

Another characteristic of sulphonic acids is their ready reduction to corresponding phenols on fusion with caustic alkali according to the reaction—



Preparations of "lignone" were fused in this way, the resulting masses being extracted with ether and evaporated. Only mere traces of ether extract were obtained, and these gave none of the usual tests for phenols. During the fusion the sulphur gave strong evidence of its escape into the air in the form of some volatile mercaptan, with a very penetrating and sickening odor.

POSITION OF THE SULPHUR IN "LIGNONE."

As in both series of tests just described the "lignone" failed to react in a way characteristic of true sulphonic acids, the presumption is reasonable that a sulphonic acid is not present. An interesting question is therefore raised. How is the sulphur in this material related to the molecule? In the salting-out experiments some light was thrown on this question. It was found that a considerable part at least of the sulphur was in such loose combination that it was given off as sulphur dioxide in the cold during the salting process. The result when first observed was attributed to the sulphur dioxide in the liquor, but it was possible to show that such was not its origin. A small amount of the fresh liquor was cautiously evaporated nearly to dryness and then diluted with water to the original volume. This solution was then salted in parallel with a fresh solution. As nearly as could be determined by the sense of smell, equal amounts of sulphur dioxide were given off by both samples. Confirmatory results were obtained by dissolving some of "lignone A," a completely dried sample, and treating it in the same manner. That all the sulphur could not be removed by this procedure was evident on drying and igniting the salted sample, when the same disgusting odor was given off as by the original sample and apparently to the same degree. This point was verified quantitatively by titration with

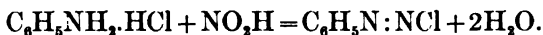
iodine solution. When the solution was acidified, an evolution of sulphur dioxide occurred and the reducing power increased from an equivalent of 0.01 per cent to 0.104 per cent of sulphur dioxide. On continued boiling without acid the reducing power increased from 0.011 to 0.015 per cent of sulphur dioxide. Boiling with potassium hydrate still further increased it to 0.201 per cent. Lime water had a similar but less marked effect. All these observations point to the probable fact that a sulphurous ether is present. Such ethers yield sulphur dioxide to sulphuric acid and are readily hydrolyzed by an alkali. The results here obtained are, in all respects, what would be expected from sulphurous ether, and the presence of a sulphonic acid has not been verified. Though the presence of the latter compound has not been disproved, the writer is strongly of the opinion that the major part, at least, of the sulphur is present in the form of an acid sulphurous ether of some complex hydrocarbon radicle.

REACTIONS WITH AROMATIC AMINES.

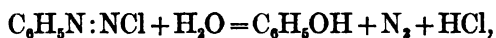
Previous investigators have generally agreed that "lignone" possesses aldehydic properties. A characteristic property of aldehydes is that of forming condensation products with certain bodies; the aldehyde and the other substance—*aniline*, for example—condense to form a complex molecule. When a solution of "lignone" was mixed with *aniline*, a bright-red precipitate was formed. An excess of *aniline* changed this body to a black insoluble gum. The reaction took place equally well with *aniline* oil or with *aniline* sulphate. All attempts to purify the product failed. It was insoluble in all solvents except acids, which apparently decomposed it into its original constituents. Reference will later be made to the action of strong nitric acid on the gum. Exactly similar condensations were observed with the following: *Ethyl aniline*, *diethyl aniline*, *dimethyl aniline*, *methyl diphenylamine*, *m-chloraniline*, *p-chloraniline*, *di-chloraniline* (1-2-4), *m-nitraniline*, *p-nitraniline*, *o-toluidine*, *p-toluidine*, *dibrom-o-toluidine*, *o-tolidine*. Substituted amines which did not give condensations were *o-nitraniline* and *dinitraniline* (1-3-5). Bright-red products were formed in every case where the amine retained the NH_2 group. With amines in which substitution had taken place in that group brown or black compounds were formed. The reactions of these preparations with fused sodium sulphide is considered under the caption "Sulphur dyes." As in the case of the *aniline* condensation product, it was not possible to purify these gummy substances. They were decomposed into the original constituents on treatment with strong acids or generally on heating.

REACTIONS OF THE AMINE CONDENSATION PRODUCTS WITH NITROUS ACID.

On the assumption that the condensation products still retain their characteristic amine group, they were treated with nitrous acid in an ice bath, in the hope of obtaining some new bodies through the diazo reaction. In the case of aniline this reaction is—



When this substance alone is heated it decomposes, yielding phenol, but in the presence of other substances, such as some unaltered aniline, reactions of technical importance can be brought about:



The product of the latter reaction is diazo-amidobenzene, a starting point for the preparation of an important group of dyes. Application of the diazo reaction to the condensation products above described did not generally result in apparent change. In some experiments an excess of the amine reacted in a manner quite characteristic of the amine itself without any substituted groups. The general inertness of these bodies under such conditions leads to the conclusion that substitution takes place in the amido group of the condensation products. This is further verified by the fact previously shown, that all primary amines gave bright-red condensation products, while the others gave brown or black substances.

REACTIONS WITH NITRIC ACID.

Concentrated nitric acid was found to have a very vigorous action on the dry "lignone" preparation and on the sulphite liquor itself at high temperatures. The organic matter of the dry "lignone" is completely oxidized, chiefly to oxalic acid, in the presence of a sufficient excess of the acid. Nitrous acid fumes are evolved, and the odor of acetic acid can be distinctly detected. The action of nitric acid on the waste liquor is less violent. When a mixture of one part strong acid and ten parts of liquor is warmed, action begins at once. Nitrous and acetic acids are evolved, as with the dry product, and the color of the solution changes from dark brown to bright, golden orange. This solution, after neutralization of the free nitric acid by an excess of sodium acetate, was found to dye wool and silk a beautiful orange-yellow. This yellow dyestuff, which for convenience may be called lignone yellow, is of peculiar interest as a product to be recovered that may be valuable, and it was therefore carefully studied.

LIGNONE YELLOW.

Difficulty was at first experienced in separating the dye from the liquid. Cloth could be dyed directly in the liquid with excellent results, but on evaporation the dye lost a great deal of its coloring power. By evaporating it in partial vacuum to a thick sirup and then reducing it to dryness in a warmed vacuum desiccator, it was finally possible to obtain the desired material in dry form. It is a light-yellow powder, very porous, and extremely hygroscopic, which latter property considerably diminishes its commercial value.

Samples of woolen cloth dyed in baths prepared from the dried material in the proportion of 2 per cent of the dye, by weight, were very beautifully colored. The color is retained on boiling for half an hour in soap solution, dilute acetic acid, or dilute alkali. It withstands the action of bleaching powder, chromate, and other oxidizing agents. It will stand direct summer sunlight for two days without apparent discoloration, but it is affected on the third day; so it is, therefore, only moderately fast to sunlight.

Lignone yellow is exceedingly soluble in water and in ethyl alcohol. On evaporation of these solutions it yields a pasty mass which is completely dried with difficulty. When dried at 100° C., it is decomposed with evolution of nitrous oxide. It can be eventually oxidized with nitric acid to oxalic acid. From the manner of its formation it might be thought to be a nitro-body and in its dyeing properties it resembles picric acid; but it differs from the latter and from other nitrophenols in several particulars. Picric acid, or tri-nitrophenol, crystallizes from hot water and is difficultly soluble in cold water. The same is true of para-nitrophenol. Ortho- and meta-nitrophenols melt at 45° C. and 96° C., respectively. The three dinitrophenols are converted to picric acid on further nitration. If lignone yellow is an aromatic nitro-body, it must be more complex than any of the nitrophenols. Repeated attempts to reduce this dye were made, but no amido-body could be detected after attempted reduction with zinc dust, zinc and hydrochloric acid, iron and sulphuric acid, ammonium sulphide, hydrogen sulphide, or the electric current. In no case did nitrous acid bring about any reaction after these attempts at reduction. Generally, the yellow color was not destroyed. Neither weak chromic acid nor bleaching powder destroy the color. Long-continued boiling of the original sulphite liquor with sodium nitrite gives a liquor with feeble dyeing properties, the color being like that of the nitrated substance. It is possible, therefore, that the dye is a nitroso-compound of some complex radicle rather than a nitro-body. All attempts to prove this point resulted negatively and the question of the fundamental character of the dye remains open.

REACTIONS OF THE AMINE CONDENSATION PRODUCTS WITH NITRIC ACID.

It was thought that the nitration of the substances produced by the condensation of the "lignone" substance with various amines might give rise to dyes of different character, and that the latter might have technical value as well as furnish some clue to the nature of lignone yellow. Accordingly, the different condensations described under "Reactions with aromatic amines" (p. 30) were submitted to the action of dilute nitric acid and the dyeing properties of the resulting solutions were tested on samples of wool. To obtain comparative results, the same quantities of the various components were used each time. As many of the amines are themselves capable of easy nitration under suitable conditions, a blank test was made each time, the amine tested being used without any sulphite liquor. The results of such blank tests as gave a dye in any way similar to that resulting from the condensation product are not recorded as positive. In each test approximately one part of the amine and one part of nitric acid were used with twenty parts of the sulphite liquor. The results of the tests are summarized in the following table:

Nitration of products resulting from the condensation of "lignone" and amines; wool dyed in resulting liquors.

Amine.	Color of dye produced.	Intensity of color.	Color of blank.
Aniline.....	Golden yellow.....	Strong.....	Colorless.
Dimethyl aniline.....	Dark yellow.....	Strong.....	Yellow.
Ethyl aniline.....	Olive green.....	Strong.....	Olive brown.
Diethyl aniline.....	Greenish yellow.....	Weak.....	Colorless.
Methyl diphenylamine.....	Lemon yellow.....	Weak.....	Brown.
<i>m</i> -Chloraniline.....	Red, washing out yellow.....	Weak.....	Pale pink.
<i>p</i> -Chloraniline.....	Reddish orange.....	Strong.....	Colorless.
Dichloraniline.....	Reddish brown.....	Strong.....	Pale orange.
<i>o</i> -Nitraniline.....	Golden orange.....	Strong.....	Colorless.
<i>m</i> -Nitraniline.....	Golden orange.....	Strong.....	Colorless.
<i>p</i> -Nitraniline.....	Dark orange.....	Strong.....	Colorless.
Dinitraniline.....	Canary yellow.....	Weak.....	Colorless.
<i>o</i> -Toluidine.....	Golden yellow.....	Strong.....	Colorless.
<i>p</i> -Toluidine.....	Dark orange.....	Strong.....	Colorless.
Dibrom- <i>o</i> -toluidine.....	Golden orange.....	Strong.....	Colorless.
<i>o</i> -Toldine.....	Brownish yellow.....	Strong.....	Purple.

With the exception of one or two doubtful cases, it appears that the condensation products enter into reaction with nitric acid just as "lignone" alone does, and that the shade and intensity of the dyes produced by the reaction vary from green through orange and yellow to brown, depending on the nature of the amine that is used. Some general observations can also be made from this study. Substitution in the amido group of ethyl aniline, etc., gives greenish shades, and the lighter the substituting groups the more pronounced the green. In mono-substituted aniline, the para-compounds give the most bril-

liant and powerful dyes, and then in decreasing brilliancy the meta- and the ortho-compounds. The most powerful and brilliant dyes of the series in the table were those produced by *p*-chloraniline, *p*-nitraniline, and *p*-toluidine. Chlor-compounds give the most brilliant dyes; the nitro-compounds give dyes of more strength and body. As with the nitrated "lignone" alone, here also every attempt failed to produce amines from their nitrated substances. Many of the products, it is true, gave a reaction with nitrous acid after reduction, but in all such cases the reaction was that of the amine originally used and the resulting substances could be prepared equally well without the addition of "lignone." Reduction of the nitraniline products was not attempted, as too great complication would arise from the presence of the nitro-groups known to be present.

SULPHUR DYES.

Many organic substances yield dyes when fused with a mixture of sulphur and sodium sulphide. These so-called sulphur dyes are now manufactured in a variety of colors. They are direct cotton dyes—that is, they dye cotton without the aid of a mordant—and they are very fast. Their cheapness and valuable properties have caused them to come into wide use. An attempt was made to prepare dyes of this kind from sulphite waste liquor and from several of its condensation products. In particular, it was hoped to obtain dyes of bright color, red or blue, because such colors are especially desirable and bring good prices on the market. Brown and black are much more readily made, and are consequently cheaper. Mixtures of one part dry crude "lignone" and one-half part each of sodium sulphide and sulphur were fused for fifteen minutes at a low heat. The resulting mass was extracted in hot water and the extract filtered and evaporated. From 25 grams of dry "lignone" there were made 20 grams of a green powder, soluble in water containing a little sodium sulphide. This powder was found to be a true sulphur dye, coloring cotton a dark green, which changed to a good black on oxidation in the air or on subsequent treatment in a chrome bath. Compared with commercial dyes in the market, this dye is worth about 7 cents a pound in its impure condition. About half its weight is inert material, which can be removed by proper treatment. Similar experiments in preparing sulphur dyes were made with the condensation products previously mentioned. (See p. 33.) The shades of the resulting dyes were somewhat modified by the presence of the amine, but they were all browns, grays, or black. No advantage was apparent in the use of the condensed products over that of the untreated "lignone."

COMMERCIAL POSSIBILITIES OF LIGNONE DYES.

Two of the best dyes, namely, those resulting from the nitration of "lignone" alone and of "lignone" condensed with *p*-chloraniline, were prepared in large quantity, in order to determine the yield and the cost of the process. One hundred grams of dry crude "lignone" were treated with 50 cubic centimeters of concentrated nitric acid (specific gravity 1.42), and the resulting solution evaporated in vacuo. Seventy grams of lignone yellow were obtained. Compared with mandarin yellow, the technical dye approaching it most nearly in color and fastness, it is worth 18 cents a pound. The cost of nitric acid would be 5 cents a pound of dye. To neglect for the moment the cost of evaporating the original liquor, the margin between the cost of the acid and the value of the dye appears to be sufficient to pay for the work of handling. This would be true at places where expediency makes it necessary to evaporate the liquor in any case, and also at places where the dye could be used in liquid form as made. The cost of evaporating the liquor, however, would undoubtedly be greater than the value of the dye. It must also be borne in mind that there is necessarily a limited market for a dye of this kind—a market too limited, in fact, to permit any general adoption of this plan of utilization, even if it were very much cheaper. A similar test of the cost, yield, and value of the dye from *p*-chloraniline gave an additional cost of 9 cents a pound of dye for aniline, making the total cost for material 14 cents a pound. While the color was much more brilliant, its red shade lowers slightly its market value, pure yellows and greenish yellows being in much greater demand for use than browns. As an additional market outlet, however, this dye may possibly help in the utilization of sulphite waste liquor. The actual results attained in this investigation are not considered so important as the fact that a new and interesting series of reactions of "lignone" have been discovered. Further development of these dyes is the work of the skilled expert in textile coloring. It is not too much to expect that such an expert, possessing full knowledge of the technique of dyeing, will be able not only to simplify and to reduce to a practical working basis the methods herein outlined, but also to discover new and more valuable products by further experimentation along similar lines.

CONCLUSION.

The foregoing study of sulphite pulp waste liquor and of the possible utilization of the organic material in it may be summarized in a few sentences.

Stream pollution by the waste from sulphite pulp mills is extensive and wasteful; every year over two and a half billion pounds of solid

matter from this source are turned into the rivers and lakes of the United States.

The problem of utilizing this immense amount of waste matter has been studied for a long time, and numerous processes for using or for destroying it have been devised, but they are all unsuccessful, either because there is only a limited market for the proposed product or because the suggested process is prohibitively costly.

Successful disposal of the sulphite waste liquor lies obviously in the utilization of the so-called "lignone" in it, but aside from the employment of this substance to a slight extent as an adhesive and as a source of tannin, no practicable way for its direct use has been devised.

The waste consists principally of wood material separated from the wood fiber by the action of a strong sulphite solution on wood chips; it is a compound of "lignone" with sulphur; but the exact nature of the union has not been definitely demonstrated.

Experimental evidence indicates that the sulphur-bearing compound in the waste liquor is not a true sulphonic acid; at all events, it does not react like an ordinary sulphonic acid. Its condensation with the aromatic amines point to its probable aldehydic nature.

Nitration of "lignone" and of its amine condensation products gives a series of dyes the shade and intensity of which vary from green through orange and yellow to brown, depending on the nature of the amine that is used. These substances dye wool directly, giving brilliant colors that are fast to soap, acids, and alkalies, and reasonably fast to sunlight. One of them, named lignone yellow, and made by nitrating crude "lignone" itself, dyes wool and silk a beautiful orange yellow. Fusion of "lignone" with sodium sulphide and crude sulphur produces a sulphur dye that colors cotton dark green, changing to black on treatment in a chrome bath.

A search for new compounds, such as that made in the present investigation, possesses the serious drawback that much time and effort may be spent without tangible results; on the other hand, an important discovery may be made at any time. Certain reactions brought to light in this work with "lignone" reveal great possibilities. Though the dye called lignone yellow has only slight commercial possibilities and is at best but a partial solution of the major problem, yet the opportunities for further progress along this line are pregnant with the ever-present chance of discovering valuable substances. The number of "lignone" condensation products is almost unlimited, and a wide field for investigation is thereby offered. Only a small portion of a large and interesting territory has been covered by these experiments and the results are by no means conclusive. But it is hoped and expected that the mere reopening of this old and practically abandoned problem by calling attention to these new lines of attack may result in renewed investigation and in the ultimate utilization of a substance that to-day is probably the most valuable waste material known to industrial chemistry.

SURVEY PUBLICATIONS ON STREAM POLLUTION.

The following water-supply papers of the Survey discuss stream pollution. Nos. 103, 152, 185, and 194 can be obtained from the Superintendent of Documents, Government Printing Office, Washington, D. C., at the prices stated. Any of the others will be sent free, while the edition lasts, on application to the Director of the United States Geological Survey.

72. Sewage pollution in the metropolitan area near New York City and its effect on inland water resources, by M. O. Leighton. 1902. 75 pp., 8 pls.
79. Normal and polluted water in northeastern United States, by M. O. Leighton. 1903. 192 pp.
103. A review of the laws forbidding pollution of inland waters in the United States, by E. B. Goodell. 1904. 120 pp. 10c. (See No. 152.)
108. Quality of water in the Susquehanna River drainage basin, by M. O. Leighton, with an introductory chapter on physiographic features, by G. B. Hollister. 1904. 76 pp., 4 pls.
113. The disposal of strawboard and oil-well wastes, by R. L. Sackett and Isaiah Bowman. 1905. 52 pp., 4 pls.
121. Preliminary report on the pollution of Lake Champlain, by M. O. Leighton. 1905. 119 pp., 13 pls.
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